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TRANSACTIONS

OF THE

NORTH-EAST COAST INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS.

EDITED BY THE SECRETARY OF THE INSTITUTION.

VOLUME III.

THIRD SESSION, 1886-87.

THE RIGHT OF PUBLICATION AND TRANSLATION IS RESERVED.

Newcastle-upon-Tyne:
ANDREW REID, PRINTING COURT BUILDINGS, AKENSIDE HILL.

1887.

ERRATA.

Page 68, *for* "Mr. J. L. Thompson," *read* "Mr. Robert Thompson."

Page 102, after formula (7) *for* "But $\pi D^2 L$ = the volume of material," *read* "$\frac{\pi}{4} D^2 L$."

Page 113, formula (37) *for* "$Z_t = \frac{\pi}{16}(D^2 - d_a^2)\sqrt{D^2 \times d_a^2}$"

read "$Z_t = \frac{\pi}{16}(D^2 - d_a^2)\sqrt{D^2 + d_a^2}$"

Page 198, first line, *for* "*Curvature of Developing Surface, etc.*," *read* "*Curvature of Blades, etc.*"

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Vol. 2, 1882.—Design of Movable Bridges. The Smith Vacuum and Automatic Vacuum Brakes. Electric Light at the Free Library, Liverpool. Preservation of Iron from Corrosion. Application of Natural Forces to the Production of Motive Power. Lamination and Defective Welds in Iron. Propulsion of Vessels by Steam direct from the Boilers, Tides and Tidal Scour. Proposed Elevated Railway for Liverpool Docks. Etc.

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MANCHESTER ASSOCIATION OF ENGINEERS, Manchester.—Sundry papers as follows:—The Progress of Printing. The use of Steam for Canal Boat Propulsion. The use and abuse of the Steam Engine Indicator. Conservation of Energy. Address: The First Iron Boat and its Inventor, John Wilkinson. Boiler Explosions. The Growth of Industries at Home and Abroad. System in Engineering Works. Thirty-first Annual Report. The Chief Mechanical Inventors of Lancashire. Lubrication.

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THE INSTITUTION OF NAVAL ARCHICTECTS, London, *Vol.* 27, 1886.—The Speed Trials of recent War Ships. An Improved Mechanical Method of finding the Stability of a Vessel. A Strain Indicator for use at Sea. A brief Review of the Progress of Mild Steel, and the result of 8 years' experience of its use for Shipbuilding purposes. The present aspect of Mild Steel for Shipbuilding. The use of Steel Castings in lieu of Iron Forgings and Brass Castings in Building and Fitting Ships. Closed Stokeholds. Forced Combustion in Furnaces of Steam Boilers. Modern Improvements in the Working of Cables and the Stowage of Anchors. Experience in Propulsion with Three Screws. The Determination of the most suitable Dimensions for Screw Propellers. Description of an Instrument intended to Analyse Rolling of Ships. Proposed Steam Life Boat, with special reference to its Stability. Converting existing Compound Engines into Triple Expansion Engines. Flexible Crank and Propeller Shafting in lieu of Rigid Shafting for Marine Propulsion. A new system of Steering Gear, and Rudder Strains recorded by it. Recent Measurements of Turning Powers of Screw Ships. The Strength of Bulkheads, etc.

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March and April.—L'Aluminium et ses Alliages (continued). Les Origines de la Métallurgie au pays d' entre-sambre-et-Meuse. Roues de Wagon. L'Application des Taquets a Abaissement de Systéme Stauss au Siége des Charbonnages de Bascoup. Note sur les Chambers d'Explications. Etc.

THE SOUTH WALES INSTITUTE OF ENGINEERS, Swansea, *Vol.* 14, *No.* 6.—Discussion on Improvements in Coal Washing. Discussion on Recent Improvements on Electric Lighting. Discussion on a Remarkable Discovery of Coal at the Kingswood Collieries, 1884. Discussion on Gregory's Improved Valve Gear. Discussion on Description of Plant for Iron Smelting by Water Gas. The Watering of Dusty Mines. Improved Hydraulic Pump for Mining Purposes. The Mechanical Telephone. Clapp & Sandbrook's Improved Safety Lamp. *Vol.* 15, *No.* 1.—Adjourned Discussion :—Electric Lighting, and Gregory's Improved Valve Gear. Discussion on the Watering of Dusty Mines. Papers :—Notes on the Coal Fields and Coal Industry of Belgium. A Method of Lighting Locked Safety Lamps. *No.* 2.—Discussions :—The Watering or Damping of Dusty Mines. An Improved Hydraulic Pump for Mining Purposes. The Mons District of the Belgium Coal-fields. A Method of Lighting Locked Safety-Lamps. Papers :—Suggested Amendment in the Economics of Coal Washing in South Wales. Mercier's Improved Safety-Lamps. Electric Safety Lamps for Miners. Portable Electric Miners' Safety-Lamps. Poetsch's Freezing System of Sinking through Quicksands. Abstract of Paper on the Use of Petroleum as Fuel in Steamships and Locomotives. *No.* 3.—Discussion on Suggested Amendment in the Economics of Coal Working in South Wales. Discussion on Electric Safety-Lamps. The Hasard Collieries at Micheroux, Belgium. Proposed Method of Extracting Gas from Fiery Seams. Shot Firing in Mines. The Severn Tunnel.

THE UNITED STATES NAVAL INSTITUTE, Annapolis, U.S., *Vol.* 12, *No.* 3.—Corrosion of the Copper of the "Juniata." Practical Method of arriving at the Number, Size, Type, etc., of the Vessels of which the United States Navy should consist in me of peace. Notes on the Literature of Explosives, etc. *No.* 4.—Range Lights on Sea-going Ships. Proposed Method of Ranging Guns applicable to Flat Trajectories. Notes on Electrical Testing and Measuring Apparatus for Ships. Naval Re-organisation. On the Study of Naval Warfare as a Science. The Firing of High Explosives from Great Guns. Compressed Gun-Cotton for Military Purposes. Notes on the Literature of Explosives. Extract from the Report of the March to Witu, etc. Forced Combustion. Etc.

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Industries.	The Engineer.
Marine Engineer.	The Practical Engineer.

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J. C. Stirzaker.
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Secretary:—J. Duckitt,
G, Exchange Buildings, King Street, Newcastle-upon-Tyne.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

List of Members, June 1st, 1887.

EXPLANATION.

(A.)	Agent and Accountant.	(N. A.)	Naval Architect.
(C. E.)	Civil Engineer.	(R. M.)	Rope Manufacturer.
(E.)	Engineer and Boilermaker.	(S.)	Shipbuilder.
(F. M.)	Forge Master.	(S. O.)	Ship Owner.
(I. & S. M.)	Iron and Steel Merchants and Manufacturers.	(SUR.)	Engineer and Ship Surveyor.

HONORARY MEMBERS.

ELECTED.

The Right Hon. Lord Armstrong, C.B., LL.D., F.R.S., Cragside, Rothbury Nov. 1884
The Right Honourable the Earl of Ravensworth, Ravensworth Castle, near Gateshead ... ... Nov. 1884
W. H. White, Esq., The Admiralty, Whitehall, London ... ... (N A) Nov. 1884

LIFE MEMBERS.

Halley, David, Burmeister & Wains, Maskin-og Skibsbyggeri, Copenhagen, Denmark ... ... (E) Feb. 1887
Macoll, H., 2, Borough Road Terrace, Sunderland ... ... (S) Nov. 1884
Spence, W. G., 66, Elswick Road, Newcastle... ... ... (E) Nov. 1884

MEMBERS.

Adamson, Alex., Palmer's Shipbuilding and Iron Co., Jarrow ... (S) Nov. 1885
Ahlbom, C., York Road, West Hartlepool ... ... (E) Nov. 1884
Aitchison, Jas., Hylton, Sunderland ... ... (S) Nov. 1884
Alchin, A. H., 89, Wood Lane, Shepherd's Bush, London ... ... (E) Jan. 1885
Allan, Jas. McNeal, 5, Edith Street, Jarrow... ... ... (E) Dec. 1886
Allan, T. J., The Green, Wallsend, Newcastle-on-Tyne ... ... (E) Nov. 1884
Allardes, Wm., 14, Upper Bars Bridge Road, Bloomfield, Belfast... (E) Nov. 1884
Allison, John, 2, St. George's Road, Leyton, London, E. ... ... (E) Nov. 1886
Almond, H. J., 43, Muralla del Mar, Cartagena, Spain ... ... (E) Nov. 1884
Anderson, A., Bright Street, Monkwearmouth, Sunderland ... ... Nov. 1884
Anderson, J., Messrs. Wigham Richardson & Co., Low Walker, Newcastle-on-Tyne ... ... Nov. 1884
Andrew, D., 31, Westmorland Road, Newcastle-on-Tyne ... (SUR) Jan. 1885
Andrews, Allan, 1, Arranmore, Dunville Avenue, Dublin, Ireland (E) Dec. 1885

		ELECTED.
Andrews, Jas.	(E)	Nov. 1884
Andrews, William, 5, Barrington Crescent, Stockton-on-Tees ...	(SUR)	Nov. 1885
Anthony, Jas., 6, Northumberland Square, North Shields ...	(S)	Oct. 1886
Appleby, W., 18, Race Street, Sandyford Road, Newcastle-on-Tyne ...		Nov. 1884
Armstrong, A., Chester Street East, Millfield, Sunderland		Nov. 1884
Armstrong, G. S., 12, Brookland Road, Hylton Road, Sunderland... ...		Nov. 1884
Arnison, Geo., Jun., 5, Tavistock Place, Sunderland ...	(N A)	Nov. 1884
Ash, Mortimer W., Ashfield Villa, Heaton Road, Heaton	(E)	Feb. 1887
Austin, S. P., Wear Dockyard, Sunderland	(S)	Nov. 1884
Bailey, James, 6, Ashfield Terrace, Ryton-on-Tyne	(E)	Nov. 1884
Bain, David, 15, Belgrave Terrace, Newcastle-on-Tyne	(E)	Oct. 1885
Baird, Alex., 23, The Retreat, Sunderland		Nov. 1884
Barley, C. J., Caterham Manor, Warlingham Station, Surrey ... ... (E)	Graduate, Member,	Feb. 1885 Dec. 1886
Bate, Edward R., 5, Ferndale Road, Clapham, London	(E)	Jan. 1885
Batey, John Thomas, 30, Richmond Street, Newcastle-on-Tyne ...	(S)	Nov. 1885
Baxter, J., 24, Clayton Park Square, Newcastle-on-Tyne	(E)	Nov. 1884
Baxter, W. J., Navy Department, Washington, U.S.A.	(E)	Oct. 1886
Beadon, D. C., Rue Martron, Rochefort sur Mer, France	(E)	Jan. 1885
Bell, James, Northern Marine Engineering Co., South Shields ...	(E)	Feb. 1887
Bell, R. T., 2, William Street, Jarrow	(S)	Nov. 1885
Bergstrom, Gus., 14, St. Hilda Street, East Hartlepool	(N A)	Mar. 1886
Berkley, A. B., Grange Villa, Jarrow	(E)	Mar. 1887
Bindisböll, S. C. W., 13, Charlotte Street, Newcastle-on-Tyne ...	(E)	Nov. 1884
Bittleston, W. H., 24, Harmer Street, Gravesend	(S)	May 1885
Black, Jas., Portobello Foundry, Sunderland	(E)	Jan. 1885
Black, Wm., Messrs. Black, Hawthorn, & Co., Gateshead	(E)	Jan. 1885
Blakston, J. W., 5, Douro Terrace, Monkwearmouth, Sunderland	(S)	Jan. 1886
Blechynden, Alfred, Barrow Shipbuilding Co., Barrow-in-Furness	(E)	Oct. 1885
Blenkinsop, John N., Lobley Hill, Gateshead	(E)	Oct. 1885
Blumer, Wm., Rockside, Roker, Sunderland	(S)	Dec. 1886
Bone, W. J., 61, Linskill Terrace, North Shields	(S)	Dec. 1884
Boolds, Jas. H., Shipyard, Pallion, Sunderland	(S)	Oct. 1886
Borovski, G., Baltic Works, St. Petersburg, Russia	(E)	Oct. 1885
Bourn, John, 1, Wincomblee, Walker	(E)	Nov. 1884
Boyd, Wm., 74, Jesmond Road, Newcastle-on-Tyne	(E)	Nov. 1884
Brankston, R. T., 37, Hawthorn Street, Newcastle-on-Tyne ...	(E)	Nov. 1884
Bray, C. H., 86, Roker Avenue, Sunderland	(E)	Mar. 1887
Bremberg, G., Kockurns Mekaniska, Verkestad, Malmo, Sweden...	(S)	Nov. 1884
Brock, John, 5, St. Mary's Place, Newcastle-on-Tyne	(E)	Nov. 1885
Brough, Robert, 9, Western Hill, Sunderland	(E)	Dec. 1885
Brown, Eugene, 125, Sandyford Road, Newcastle-on-Tyne ...	(E)	Feb. 1886
Brown, Nigel K., 31, Grange Road West, Jarrow	(E)	Nov. 1884
Browne, Sir B. C., 2, Granville Road, Jesmond, Newcastle-on-Tyne	(C E)	Jan. 1885
Brown, William, 3, Lower Prospect Place, Pembroke Dock ...	(E)	April 1887

		ELECTED.
Brown, T. R., 14, Dock Street East, Sunderland ...	(E)	Graduate, May 1885 Member, Oct., 1866
Buchanan, A., Messrs. Swan & Hunter, Wallsend	(S)	Nov. 1884
Buckland, H. B., Walker Boiler Works, Low Walker	(E)	Nov. 1885
Buglass, A. W., 54, Milburn Terrace, Monkwearmouth, Sunderland ...		Nov. 1884
Bulmer, John, 1, Graingerville North, Newcastle-on-Tyne ...	(E)	Mar. 1886
Burdon, J. G., 46, Lovaine Place, Newcastle-on-Tyne	(E)	Nov. 1884
Burns, J., 8, Kaiser Terrace, West Hartlepool		Nov. 1884
Butterfield, George, 30, John Candlish Road, Millfield, Sunderland ...		Nov. 1884
Campbell, Hartley, Sunderland Engine Works, Sunderland ...	(E)	Nov. 1884
Carnegie, Alexander, 65, Gloucester Road, Newcastle-on-Tyne ..	(S)	Nov. 1884
Carr, J. W., Point Pleasant House, Wallsend	(E)	Feb. 1885
Carr, Thomas, Messrs. Carr & Co., Engineers, Sunderland ...	(E)	Feb. 1887
Carrick, H., Holly House, Gateshead	(E)	Nov. 1884
Carrick, Henry H., Holly House, Gateshead	(E)	Nov. 1885
Carter, G. J., Elswick Shipyard, Newcastle-on-Tyne	(S)	Dec. 1886
Carter, Thos., 7, Dundas Street, Monkwearmouth, Sunderland ...	(E)	Nov. 1884
Cay, Arthur, Westoe, South Shields	(E)	Nov. 1884
Chapman, Capt., Belle Vue, Low Fell, Gateshead	(E)	Nov. 1884
Chapman, Hedley, 147, Park Road, Newcastle-on-Tyne	(E)	Feb. 1886
Charlton, Henry, Messrs. Hawks, Crawshay, & Sons, Gateshead ...	(E)	Nov. 1884
Charlton, R. B., Jun., Manors Railway Station Works, Newcastle	(E)	Nov. 1884
Charlton, T., 25, Lincoln Street, Gateshead	(E)	Nov. 1884
Christie, C. A., 4, Colbeck Terrace, Tynemouth	(E)	Nov. 1884
Christie, C. J. D., Neptune Works, Low Walker	(S)	Nov. 1884
Christie, J. D., 4, Colbeck Terrace, Tynemouth	(S)	Nov. 1884
Clark, Geo., Southwick Engine Works, Sunderland	(E)	Nov. 1884
Clarke, Jas., Elswick Marine Engine Works, Newcastle-on-Tyne	(E)	Nov. 1884
Clarke, Thos., Elswick Marine Engine Works, Newcastle-on-Tyne	(E)	Nov. 1884
Collyer, P. N., Hurworth-on-Tees, Darlington	(E)	Feb. 1887
Conning, Alfred C., Dunston Iron and Steel Works, Gateshead ..	(F M)	May 1885
Conradi, Carl, Hawthorn, Leslie & Co., St. Peters'	(E)	Nov. 1884
Coote, Arthur, Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn	(S)	Nov. 1884
Crawford, Jas., 9, Custom House Court, Quayside, Newcastle ..	(SUR)	Nov. 1886
Crawford, W. A. F., 18, Wentworth Place, Newcastle-on-Tyne ...	(E)	Nov. 1884
Cross, Wm., 4, Fenham Terrace, Newcastle-on-Tyne	(E)	Mar. 1886
Cruddas, W. D., Messrs. Armstrong, Mitchell, & Co., Elswick ...	(E)	Dec. 1884
Cuevel, John L., 65, Eldon Street, Newcastle	(E)	Mar. 1886
Cummins, W. R., Neptune Engine Works, Low Walker	(E)	Nov. 1884
Cutter, W., Messrs. Armstrong, Mitchell, & Co., Elswick	(E)	Nov. 1884
Dacres, T. H., 14, De Grey Street, Newcastle	(E)	Mar. 1887
Dale, Francis Allen, 25, Whickham Street, Monkwearmouth, Sunderland	(E)	Nov. 1884
Dalrymple, Wm., Hawks, Crawshay, & Sons, Gateshead	(E)	Dec. 1886

		ELECTED.
Darling, W. J., Lloyd's Surveyor, Leith	(S)	April 1887
Darley, Henry, 98, Park Road, Newcastle	(S)	Oct. 1886
Darney, John, Messrs. Short Bros., Pallion, Sunderland	(S)	Nov. 1884
Davis, F. B., 11, Sydenham Terrace, Newcastle-on-Tyne	(S)	Jan. 1885
Davison, John, 4, Dean Terrace West, Southwick, Sunderland ...	(E)	Nov. 1884
Davison, John W., The Crescent, Low Fell, Gateshead	(E)	Nov. 1886
Dempsy, S., Wallsend Slipway and Engineering Co., Wallsend ..	(S)	Nov. 1884
Derby, J. W., Messrs. J. & G. Thompson, Clyde Bank, Glasgow ...	(E)	Nov. 1884
Dick, Francis, 21, William Street, Stratford, London, E.	(E)	Nov. 1885
Dickinson, F. T., Park House, Sunderland ... ... (E)		Graduate, May 1885 Member, Oct., 1886
Dickinson, James, Park House, Sunderland	(E)	Nov. 1884
Dickinson, John, Park House, Sunderland	(E)	Nov. 1884
Dickinson, W., Park House, Sunderland	(E)	Nov. 1884
Dixon-Brown, L. D., Unthank Hall, Haltwhistle	(S)	Nov. 1886
Dixon, Frederick, Hebburn Villa, Hebburn	(E)	Nov. 1884
Dobeson, N. W., The Teams, Gateshead	(E)	Nov. 1884
Dobeson, T., The Teams, Gateshead	(E)	Nov. 1884
Donald, James, Pallion Road, Pallion, Sunderland	(S)	Nov. 1884
Donovan, J. W., 4, Elizabeth Street, Newcastle Road, Sunderland	(E)	April 1885
Down, T. B., 24, George's Road, Elswick, Newcastle-on-Tyne ...	(E)	Nov. 1884
Dowsen, Chas., 4, Deckham Terrace, Mount Pleasant, Gateshead	(E)	Dec. 1885
Doxford, Charles, D., Sashbrooke Terrace, Sunderland	(S)	Nov. 1884
Doxford, R. P., Pallion Engine Works, Sunderland	(E)	Nov. 1884
Doxford, W. T., Grinden Hall, Sunderlan	(S)	Nov. 1884
Drakenberg, J. A., Barrow Shipbuilding Co., Barrow-in-Furness	(E)	Feb. 1886
Duckitt, Jno., Exchange Buildings, King Street, Newcastle ...	(E)	Nov. 1884
Dudgeon, F. S., 112, Fenchurch Street, London, E.C.	(E)	Feb. 1885
Dugdale, W. H., 8, Ridley Villas, New Bridge Street, Newcastle	(E)	Dec. 1886
Dykes, James, 78, Dilston Road, Newcastle-on-Tyne	(E)	May 1885
Eckmann, John, Sunderland Engine Works, Sunderland	(E)	May 1885
Edmiston, Jas. B., Ivy Cottage, Highfield Road, Liverpool ...	(E)	Nov. 1886
Edwards, G. S., Northumberland Shipyard, Howdon	(S)	Nov. 1884
Elliott, Consitt, 4, Suffolk Street, Sunderland	(E)	May 1885
Engelbach, Herbert R., Messrs. Armstrong, Mitchell, & Co., Elswick Works	(E)	Nov. 1884
Evans, Henry A., 16, Windsor Terrace, Gateshead	(E)	Mar. 1887
Evers, G., Germania Werft, Kiel, Germany	(S)	Nov. 1884
Fairman, A. E., 23, St. Bede's Terrace, Sunderland...	(NA)	Oct. 1886
Fairweather, C. W., Ernest Scott & Co., Close, Newcastle	(E)	Dec. 1886
Farina, A. J., Oakwood House, Westmorland Road, Newcastle ...	(E)	Nov. 1884
Farquharson, R. Nesham, Old Blundells, Tiverton, Devon	(E)	Nov. 1884
Fisher, John, 46, Croft Terrace, Jarrow ... ... (S)		Graduate, Nov. 1884 Member, Dec. 1886

		ELECTED.
Fitzgerald J. F. G., 81, Wharncliffe Street, Newcastle-on-Tyne	(E)	Nov. 1884
Fleming, Charles Edward, 71, Elswick Road, Newcastle-on-Tyne	(E)	Nov. 1884
Fletcher, James, 74, Old Dumbarton Road, Glasgow	(E)	Dec. 1885
Fletcher, Robert, Walker Forge, Low Walker	(F M)	Dec. 1886
Flohr, Justus, 32, Birkencellies, Stettin, Germany	(E)	Oct. 1886
Foley, Nelson, Hotel Britannique, Naples, Italy	(E)	Nov. 1884
Forbes, John, "Blanco Enclada," Chilian Navy, Valparaiso ...	(E)	Oct. 1885
Foster, G. E., 23, Holly Street, Jarrow	(E)	Jan. 1886
Foster, Henry, Newburn Steel Works, Newburn	(E)	April 1885
Fothergill, J. R., 1, Bathgate Terrace, West Hartlepool	(E)	Mar. 1886
Fownes, Henry, Tyne Forge Co., Limited, Ouseburn, Newcastle	(F M)	Nov. 1884
Franki, J. P., Morts Dry Dock & Engineering Co., Ltd., Sydney, N.S.W., Australia	(E)	Jan. 1886
Furneaux, J. B., Victoria Works, Gateshead	(E)	Nov. 1885
Furness, John, 24, Falconar Street, Newcastle-on-Tyne	(E)	Nov. 1885
Furse, Fred., Hawthorn, Leslie, & Co., St. Peter's	(E)	April 1887
Gad, Oscar, 27, Western Hill, Sunderland	(S)	April 1885
Gannaway, H. G., 17, Caroline Street, Jarrow	(S)	Nov. 1884
Garratt, H. A., c/o Mrs. W. Stewart, Rosehill, Willington-on-Tyne	(E)	Graduate, Nov. 1884 Member, Nov. 1886
Garrett, G. H., R. Stephenson & Co., South Street, Newcastle ...	(E)	Oct. 1886
Gibson, W. F., 14, Alexandra Terrace, Hylton Road, Millfield, Sunderland		Nov. 1884
Gibson, H., 16, Stansfield Street, Monkwearmouth Sunderland ...	(S)	Nov. 1884
Gibson, W. H., 37, Tatham Street, Sunderland	(E)	Nov. 1884
Gilroy, Thomas R., Messrs. Harland & Wolff, Belfast	(E)	Nov. 1886
Glencross, Thos., 11, Ryehill, Newcastle-on-Tyne	(E)	Feb. 1885
Glover, Terrot, 6, Azalea Terrace, Sunderland	(E)	Mar. 1886
Graham, Edwin, Messrs. Osborne, Graham, & Co., Hylton, Sunderland	(S)	Nov. 1884
Graham, Joseph, 32, Brookland Road, Sunderland	...	Nov. 1884
Graham, Wm., Ford Lodge West, South Hylton, Sunderland ...	(S)	Nov. 1884
Grant, John Macpherson, 63, Westmorland Road, Newcastle ...	(E)	Nov. 1884
Gravell, John, Custom House Court, Quay, Newcastle-on-Tyne ...	(SUR)	Nov. 1884
Green, W. G., Messrs. Palmer & Co., Jarrow	(E)	Nov. 1884
Green, William, Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne	(E)	Oct. 1885
Greener, G. W., 110, George's Road, Newcastle-on-Tyne	(E)	Nov. 1884
Grey, James		Nov. 1884
Grier, Jas., 1, Ravenstown Terrace, South Shields		Nov. 1884
Grieves, Robert, 38, Linskill Terrace, North Shields	(S)	Graduate, Nov. 1884 Member, Dec. 1886
Gulston, A., 55, Holly Avenue, Jesmond, Newcastle-on-Tyne ...	(E)	Dec. 1884
Hall, Edward, 30, Ellison Place, Jarrow	(S)	Nov. 1885
Hall, J. Percy, Mayfield Villa, Jarrow	(E)	Oct. 1885

	ELECTED.
Hamilton, R. R., Rose Cottage, Willington Quay	(E) Nov. 1884
Hamilton, John, 81, Charlotte Street, Carlisle	(E) Nov. 1886
Hansen, F. T., 3, Villa Place, Union Lane, Gateshead	(E) Nov. 1884
Harding, J. C., 14, Pilgrim Street, West Hartlepool	(E) Nov. 1884
Harkness, Richard, Stephenson Street, Willington Quay	(S) Nov. 1884
Harlow, F., 135, Portland Road, Newcastle-on-Tyne	... Nov. 1884
Harman, Bruce, 10, Hamilton Terrace, West Partick, Glasgow ...	(E) Oct. 1886
Harper, J. H., 47, Grey Street, Tynemouth Road, North Shields ...	(E) Jan. 1885
Harrold, Alexander, 19, Lawton Street, Newcastle-on-Tyne ...	(E) Nov. 1884
Hartness, J., East Boldon, near Sunderland	(E) Nov. 1884
Haver, Arthur H., 15, Howarth Street South, Hylton Road, Sunderland	(S) Nov. 1884
Headlam, Robert, 5, Edward Street, Stockton-on-Tees	(E) Nov. 1886
Hebden, Sylvester, 77, Westmorland Road, Newcastle-on-Tyne ...	(E) Nov. 1884
Heck, John H., Lloyd's Registry, Aberdeen, N.B.	(S) Nov. 1885
Henderson, George, 54, Westmorland Road, Newcastle-on-Tyne ...	(E) Nov. 1884
Henderson, George, 29, Hylton Street, Sunderland	(E) Nov. 1884
Henderson, G. B., 23, Holmside, Borough Road, Sunderland ...	(E) Nov. 1884
Henderson, Robert, 11, Hadrian Road, Wallsend	(S) Nov. 1884
Hepburn, Alex., Grosvenor Place, Jesmond, Newcastle-on-Tyne ...	(E) Dec. 1885
Hepple, William, Slipway, North Shields	(E & S) Oct. 1885
Hildrey, A. J., 11, Chester Street, Sunderland	(S) Nov. 1884
Hill, Maxwell, Messrs. Palmer & Co., Jarrow, ...	(S) Nov. 1884
Hindhaugh, C. W., 59, Bedford Street, North Shields	(S) Nov. 1884
Hindson, William, 3, Claremont Park, Gateshead	(E) Nov. 1884
Hirst, Richard, 4, Cleveland Road, North Shields	(E) Nov. 1885
Hodge, R. F. W., Messrs. Schlesinger, Davis, & Co., Wallsend ...	(S) Nov. 1885
Hök, Wilhelm, Deptford Shipyard, Sunderland	(S) Oct. 1886
Homji, A. C. N., Gordon Mills, Byculla Flats, Bombay, India ...	(E) Nov. 1884
Hooper, Ernest, 5, John Candlish Road, Millfield, Sunderland ...	(E) Nov. 1885
Hopper, R. Ambrose, Messrs. M. Pearse & Co., Stockton-on-Tees ...	(S) Feb. 1886
Howie, James, Gordon Terrace, Southwick, Sunderland	(E) Nov. 1884
Hunter, George B., Messrs. Swan, Hunter, & Co., Wallsend ...	(S) Nov. 1884
Hunter, J. W., 36, Blandford Street, Sunderland	(E) May 1885
Hunter, Summers, Rosehill Terrace, Howdon-on-Tyne	(E) Nov. 1885
Hunter, Wm. Gallon, 1, Granville Terrace, West Hartlepool ...	(S) Dec. 1885
Hutchinson, C. W., 52, Westmorland Road, Newcastle-on-Tyne ...	(E) Nov. 1884
Huxham, J. L., 14, Clare Terrace, Falmouth	(S) Nov. 1884
Hymers, Richard, 197, Norfolk Road, Byker	(E) Mar. 1887
Inglis, John, Jun., Pointhouse Shipyard, Partick, Glasgow ...	(E) Oct. 1886
Inglis, John, Ramage & Ferguson, Leith	(S) April 1887
Irwin, J. H., Sunderland Engine Works, Sunderland	(E) Nov. 1884
James, M. C., 14, Windsor Terrace, Gateshead	(S) Nov. 1884
Jamieson, John, Regent Street, Hartlepool	(E) Nov. 1885
Jobling, J. C., 1, Brandling Place West, Newcastle-on-Tyne ..	(E) Nov. 1884

ELECTED.

Jobling, W. J., Lombard Street, Newcastle-on-Tyne ... (E & S O) Nov. 1884
Johnson, George, 31, Caroline Street, Jarrow ... ... (E) Nov. 1885
Johnson, John, 80, Dock Street East, Sunderland ... ... (S) May 1885
Johnson, R., 2, Blandford Street, Sunderland ... ... (S) Nov. 1884
Johnson, T. Allan, 20, Harley Street, Barrow-in-Furness ... ... (S) Nov. 1884
Johnstone, William, 7, Hamilton Terrace West, Patrick, Glasgow, N.B. ... ... (SUR) Nov. 1884

Kean, James, 3, Croft Terrace, Jarrow ... ... (E) Nov. 1884
Keen, H. A., 7, Brighton Terrace, Copland Road, Govan, Glasgow ... (E) Jan. 1886
Keene, H. R., 35, Church Street, Pembroke Dock ... (E) { Graduate, May 1885 / Member, April 1887
Key, Alexander, Mersey Chambers, Liverpool ... ...(SUR) Nov. 1884
Kilvington, W., Northumberland Engine Works, Wallsend ... (E) Nov. 1884
Kirkaldy, John, 40, West India Dock Road, London ... ... (E) Nov. 1885

Laidley, R. W., 18, Claremont Place, Newcastle ... ... (E) April 1887
Laing, Arthur, Deptford Yard, Sunderland ... ... (S) Nov. 1884
Laing, Jas., Jun., Deptford Yard, Sunderland ... ... (S) Nov. 1884
Laing, John, Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's (E) Nov. 1884
Larkin, James, East Jarrow ... ... (E) Nov. 1884
Leddicoat, Frederick, 5, Cromwell Terrace, Gateshead ... ... (E) Oct. 1885
Lewis, Henry W., Llwynynhess, Abercanaid, near Merthyr, Glamorganshire, Wales... ... ... (E) Nov. 1885
Lewis, R. A., Newburn Steel Works, Newburn ... ... (E) Nov. 1884
Liddell, A. R., 52, Mount Pleasant, Barrow-in-Furness ... ... (S) Nov. 1884
Liddell, J., Messrs. Denny & Co., Engine Works, Dumbarton ... (E) Nov. 1884
Lindfors, H., P.O. Box, 752, Norwalk Comm., U.S. America ... (S) Oct. 1886
Livingston, Thos., 4, St. John's Terrace, Jarrow ... ... (S) Nov. 1884
Livingstone, John, 25, Grove Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
Lohmeyer, H., 29, Choppington Street, Elswick, Newcastle ... (E) Nov. 1884
Long, A. E., 124, Albert Road, Jarrow ... ... (S) Nov. 1884
Lynn, J., St. Luke's Engine Works, Sunderland ... ... (E) Nov. 1884

Maccoy, John, 7, Beaumont Street, North Shields ... ... (E) Feb. 1886
Macdonald, James, jun., 7, Claremount Street, Glasgow ... ... (E) Dec. 1886
Mace, W., 253, Albert Road, Jarrow ... ... (E) Jan. 1886
MacHaffie, John, Cohoes, New York, U.S. America ... ... (E) Dec. 1885
Macoll, D. C., 14, Connaught Terrace, Jarrow ... ... (S) Nov. 1884
Manuel, G. W., Fern Bank, Catford Hill, London ... ... (E) Dec. 1885
Marlborough, Richard, 18, Elgin Street, Sunderland ... ... (S) Nov. 1884
Marr, James, 6, Ash Place, Sunderland ... ... (S) Nov. 1884
Marshall, F. C., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's (E) Nov. 1884
Marshall, R. J., 32, Mariners' Cottages, South Shields ... ... (E) Mar. 1887
Martens, D., 52, Kent Street, Jarrow ... ... (E) Mar. 1887
Mastaglio, W. D., 45, Gloucester Street, Newcastle-on-Tyne ... (E) Nov. 1885

		ELECTED.
Matthews, A., The Baths, Blyth	(E)	Nov. 1884
Matthews, Jas., Messrs. Hawthorn, Leslie, & Co., Forth Banks, Newcastle	(E)	Oct. 1886
Maughan, Wm., 15, Addison Street, Heaton...	(E)	Mar. 1887
McDouall, H. B., 118, Park Road, Newcastle-on-Tyne	(E)	Nov. 1884
McGlashan, Arch., 26, Milton Street, West Hartlepool	(S)	Nov. 1885
McIlvenna, J. G., Myrtle House, Westoe Lane, South Shields ...	(S)	Nov. 1884
McIntyre, John, 3, Abbotsford Terrace, Newcast'e-on-Tyne ...	(S O)	Jan. 1885
McKay, Jno., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's	(E)	Nov. 1884
Menzies, Wm., The Side, Newcastle-on-Tyne	(E)	Nov. 1884
Messenger, Thomas, 2, Clarence Lawn, Dover, Kent	(E)	Mar. 1887
Metcalfe, C. S., 38, Frederick Street, Sunderland	(E)	Nov. 1884
Metcalf, J. C., 22, St Vincent Street, Sunderland	(SUR)	Nov. 1884
Millar. Thos., 28, Wilberforce Street. Wallsend	(S)	Nov. 1884
Milne, W. J., 19, Fisher Street, Walker	(S)	Nov. 1884
Milton, J. T., Messrs. Hawthorn, Leslie, & Co., St. Peter's ...	(E)	Nov. 1886
Mitchell. Chas., Jesmond Towers, Newcastle-on-Tyne	(S)	Nov. 1884
Moffat, D., 36, Falconar Street, Newcastle-on-Tyne	(E)	Nov. 1884
Moffitt, Robert, 13, Grace Terrace, Sunderland	(E)	Dec. 1885
Morgan, W. H., 117, Denmark Street, Heaton, Newcastle-on-Tyne	(E)	Nov. 1884
Mörk, Paul, 3, Hawthorn Street, Newcastle-on-Tyne	(E)	Nov. 1884
Morison, D. B., 9, South Crescent, Hartlepool	(E)	Feb. 1885
Morrison, Jas., 27, Dilston Road, Newcastle-on-Tyne		Nov. 1884
Morrison, Robt., 5, Challoner Terrace, South Shields	(E)	Nov. 1886
Mowat, John, 3, Cooper Street, Monkwearmouth, Sunderland ...	(S)	Nov. 1884
Mudd, Thomas, Central Marine Engine Works, West Hartlepool	(E)	Mar. 1886
Muir, J. M., Messrs. Wigham Richardson & Co., Low Walker		Nov. 1884
Muir, Robert, 17, Westmorland Road, Newcastle	(SUR)	Oct. 1886
Myles, David, Neptune Engine Works, Low Walker	(E)	Nov. 1884
Nance, A. J., 14, Stacy Road, Routh, Cardiff	(E)	April 1887
Napier, W. E., 129, Park Road, Newcastle	(E)	Nov. 1884
Newton, W. A., Broughton Road, South Shields ...	(E)	Graduate, May 1885 Member, Oct. 1886
Nichol, B. G., 49, Leazes Terrace, Newcastle-on-Tyne	(E)	Nov. 1884
Nichol, Thos., 50, Ripon Street, Monkwearmouth, Sunderland	(SUR)	Nov. 1884
Nicholson. W. E., Messrs. Nicholson Bros., Boiler Makers, Hebburn	(E)	Nov. 1884
Nicol, John M., 10, Linskill Place, North Shields	(E)	Nov. 1884
Nicolaus, Julius, Messrs. Harland & Wolff, Belfast, Ireland ...	(E)	Nov. 1884
Nicolson, J. T., 20, Thirlstane Road E., Edinburgh	(E)	Nov. 1884
Norman, W. S., Tyne Pontoon and Dry Docks Co., Low Walker	(E)	Nov. 1884
Noton, F. R., 32, Azalea Terrace, Sunderland	(S)	Nov. 1884
O'Neil, J. J., 23, Howard Street, Sunderland	(E)	Nov. 1884
Oxley, G., Station Road, Howdon		Nov. 1884
Parkin, Rd., Messrs. Donkin & Nichol, St. Andrew's Works, Gallowgate, Newcastle	(E)	Nov. 1884

		ELECTED.
Patterson, Jas., The Green, Wallsend	(E)	Nov. 1884
Pattison, Jos., 2, Church Terrace, Wallsend	(E)	Nov. 1884
Paulson, John, 85, Tynemouth Road, Heaton, Newcastle	(S)	Feb. 1886
Pearson, James John, 22, Milton Street, Newcastle-on-Tyne ...	(E)	Feb. 1886
Penny, A. W., 69, Percy Road, Whitley	(S)	Nov. 1884
Penny, R. H., 15, Azalea Terrace South, Sunderland	(S)	Nov. 1884
Petree, James, 24, Harrison Street, Barrow-in-Furness	(S)	Oct. 1885
Phillipson, M., 12, Dame Dorothy Street, Sunderland	(E)	Nov. 1884
Phillipson, Roland, Tynemouth	(E)	Dec. 1884
Phillips, Walter, 3, West Grove Terrace, Greenwich, London ...	(E)	Oct. 1886
Phorson, P., 86, Roker Avenue, Sunderland	(S)	Nov. 1884
Pickering, Thos., 25, Ford Street, Sunderland	...	Nov. 1884
Pilcher, F. J., 3, City Buildings, Old Hall Street, Liverpool ...	(S)	April 1887
Pilling, J., 11, Rosslyn Terrace, Chester Road, Sunderland ...	...	Nov. 1884
Plews, G. W., Elswick Ordnance Works, Elswick	(E)	Nov. 1884
Plotnicki, E. C., 10, West Percy Street, North Shields	(E)	Nov. 1886
Potts, John George, 8, Gladstone Street, Sunderland	(E)	Nov. 1884
Potts, T. T., 2, South Cliff, Roker, Sunderland	(E)	Jan. 1886
Price, John, 6, Osborne Villas, Jesmond, Newcastle-on-Tyne ...	(S)	Nov. 1884
Prince, Alfred, Kent Villa, Jarrow	(E)	Nov. 1884
Pryor, Benjamin, 20, Lawton Street, Newcastle-on-Tyne	...	Nov. 1885
Purdy, A. J., ...	...	Nov. 1884
Purves, David, Lloyd's Registry, White Lion Court, London	(SUR)	Dec. 1885
Purvis, John, 1, Broughton Road, South Shields	(E)	Dec. 1886
Putnam, T., Darlington Forge, Darlington	(F M)	Nov. 1884
Putnam, William, Darlington Forge, Darlington	(F M)	Nov. 1884
Rae, John, 4, Grey Street, Glasgow, N.B.	(E)	April 1886
Ramage, J. T., The Hawthorns, Leith, N.B.	(E)	April 1887
Ramsay, W. G., 10, Stanhope Road, Tyne Dock	(E)	Mar. 1887
Ramsay, C. W., Hornsborg, Lgungby, Sweden	...	Nov. 1884
Rankine, Jno., 21, Payne Street, North Shields	(E)	Nov. 1884
Readhead, Jas., Argyle Terrace, South Shields	(S)	Nov. 1884
Readhead, R., Sea View, South Shields	(E)	Nov. 1884
Readhead, John, 18, Thomas Street, South Shields	(E)	Mar. 1886
Redhead, John, 9, Spring Street, Barrow-in-Furness	(E)	Feb. 1886
Readhead, W. B., Sea View, South Shields	(S)	Nov. 1886
Readhead, John, Jun., J. Readhead & Sons, South Shields ...	(E)	Mar. 1886
Reed, J. W., Palmer's Shipbuilding Co., Jarrow	(E)	Nov. 1884
Reed, T. A., 1, St. John's Terrace, Jarrow	(C E)	Mar. 1887
Rendal, L. J., 61, Westmorland Road, Newcastle-on-Tyne ...	(E)	Mar. 1887
Rennoldson, C., care of Messrs. J. P. Rennoldson & Sons, South Shields	(S)	Jan. 1886
Rennoldson, Jos. M., Messrs. J. P. Rennoldson & Sons, South Shields	(S)	Feb. 1886
Reynolds, W. G., 17, Ashfield Terrace East, Newcastle-on-Tyne ...	(E)	Oct. 1886
Richardson, Wigham, Neptune Works, Low Walker	(S)	Nov. 1884
Ridley, J. C., 3, Summerhill Grove, Newcastle-on-Tyne	(E)	Nov. 1884

ELECTED.

Ridley, J. H., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's (E) Nov. 1884
Ripley, P. E., Messrs. Ransomes, Sims, & Jefferies, Orwell Works, Ipswich ... ... (E) Nov. 1884
Ritson, M., 3, Mowbray Terrace, Sunderland ... ... (E) Nov. 1884
Robinson, B. A., 5, The Knoll, Sunderland ... ... (E) Nov. 1884
Robson, John H., Gallowgate Baths, Newcastle-on-Tyne ... ... (E) Nov. 1885
Robson, J. M., care of W. Whyte, B, Lombard Street, Newcastle... (E) Nov. 1884
Robson, M., 4, Dock Street, Monkwearmouth, Sunderland ... (S) Nov. 1884
Robson, Arthur, J. Blumer & Co., Sunderland ... ... (S) Dec. 1886
Robson, Thos., 14, Richmond Crescent, Barnsbury, London, N. ... (S) Nov. 1886
Ropner, Robert, jun., Preston Hall, Stockton-on-Tees ... ... (S) Feb. 1886
Rowan, Jas., 231, Elliott Street, Glasgow ... ... (E) Nov. 1886
Rowell, G. W., 22, Durham Street, Newcastle-on-Tyne ... ... (E) Feb. 1885
Rowell, H., Jesmond Gardens, Newcastle-on-Tyne ... ... Nov. 1884
Roylance, E. H., E. Scott & Co., Close, Newcastle-on-Tyne ... (E) Dec. 1886
Rusden, L., 11, Mistletoe Road, Jesmond, Newcastle-on-Tyne (E) Nov. 1884
Rutherford, T. A., c/o Messrs. Harland & Wolff, Belfast ... ... (S) Nov. 1884
Rutherford, G., Wallsend Slipway Co., Engine Works, Cardiff ... (S) Oct. 1886
Ryder, C. L., 58, Fern Avenue, Newcastle-on-Tyne... ... ... (E) Oct. 1886

Salmon, P., St. Bede's Park, Sunderland ... ... (SUR) Nov. 1884
Sanderson, J., 31, Park Road, Jarrow ... ... (S) Nov. 1884
Sandison, M., 34, Park Road, Newcastle-on-Tyne ... ... (E) Dec. 1884
Sawyers, John, Thos. Wilson, Sons, & Co., Hull ... ... (E) Oct. 1886
Schaeffer, A. G., 38, Eldon Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
Scotson, Alf., 10, Holmside, Sunderland ... ... (S) Feb. 1887
Scotson, Wm., 66, Osgathorpe Road, Sheffield ... ... (E) Nov. 1884
Scott, Ernest, Close Works, Newcastle-on-Tyne ... ... (E) Nov. 1884
Scott, Wm., 5, Osborne Terrace, Newcastle-on-Tyne ... ... Nov. 1884
Scorer, G. S., Messrs. T. & W. Smith, North Shields ... ... (S) Jan. 1885
Seabury, Edward, 40, West India Road, Limehouse, London, E. (E) Mar. 1886
Shand, H., 41, Grosvenor Place, West Jesmond, Newcastle ... (E) Nov. 1884
Sharer, E., Shipyard, Pallion, Sunderland ... ... (S) Oct. 1886
Sharp, A. E., Albert Terrace, Jarrow ... ... (E) Nov. 1884
Sharpe, W. L., 3, St. Nicholas' Buildings, Newcastle ... (SUR) Nov. 1884
Shaw, Jas., 24, Blyth Terrace, Gateshead ... ... (E) Jan. 1885
Sheppard, W. O., Pottery Lane, Newcastle-on-Tyne ... ... (E) Mar. 1887
Shevill, W. H., Avenue Terrace, Sunderland ... ... Nov. 1884
Shiells, Jas., 22, Tunstall Vale, Sunderland ... ... (E) Graduate, May 1885; Member, Oct. 1886
Shilston, Thomas, 14, Wentworth Place, Newcastle-on-Tyne (SUR) Nov. 1885
Shotten, John W., 36, Heaton Park Road, Newcastle ... (SUR) Nov. 1886
Short, J. Y., 49, West Sunniside, Sunderland ... ... (S) Nov. 1884
Short, Jos., 49, West Sunniside, Sunderland ... ... (S) Nov. 1884
Sievewright, G. W., 5, Radcliffe Terrace, Hartlepool ... ... (S) Nov. 1886
Sinclair, R., care of J. R. C. Sinclair, Esq., 2, West Quay, Greenock (E) Nov. 1884

ELECTED.

Sinton, John K., 7, Grasmere Terrace, Gateshead ... ... (E) Nov. 1885
Sisterson, G. R., 247, Hamilton Street, Newcastle-on-Tyne ... (E) Nov. 1884
Sjögren, H., Kockum's Mekamiska, Verkstad, Malmo, Sweden ... (S) Nov. 1884
Smith, Eustace, 5, Queen Street, Newcastle-on-Tyne ... ... (S) Nov. 1884
Smith, J. ... ... Nov. 1884
Smith, R. J., 2, West Lawn, Sunderland ... ... (E) Nov. 1884
Smith, Thomas Edward, Messrs. John Smith & Sons, Newgate Street, Newcastle-on-Tyne ... ... (E) April 1885
Smith, Wm., 51, Dock Street East, Sunderland ... ... (E) Nov. 1884
Soliani, Nabor, Connitato Pei Designa delle Navi Ministero dilla Marina, Roma, Italy ... ... (S) Jan. 1885
Soulsby, J. C., 2, Stacy Road, Cardiff ... ... (SUR) Nov. 1886
Spencer, John C., Walbottle Hall, near Newcastle-on-Tyne (I & S M) Dec. 1885
Spencer, J. W., Newburn Steel Works, Newburn -- ... ... (E) Feb. 1885
Spencer, R. E. E., 4, Malvern Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
Spencer, Ralph, Newburn Steel Works, Newcastle-on-Tyne ... (E) Oct. 1886
Spiers, James ... ... Nov. 1884
Stafford, William, Dunston-on-Tyne ... ... (E) Nov. 1885
Stephenson, C., 4, Mount Stuart Square, Cardiff ... ... (S) Nov. 1884
Stevenson, Wm., 25, Argyle Place, Partick, Glasgow ... ... (E) Nov. 1884
Stevenson, R. ... ... (E) {Graduate, Mar. 1886 / Member, Oct. 1886
Stirzaker, J. C., Fenham House, Brighton Grove, Newcastle ... (E) Nov. 1884
Stokoe, Thomas, 4, Lower Archer Street, West Hartlepool ... (S) Dec. 1885
Stone, Wm., 13, Rosslyn Terrace, Sunderland ... ... Nov. 1884
Stuart, G. W., 70, Coronation Street, Sunderland ... ... Nov. 1884
Stubbings, James, Cornhill, Sunderland ... ... (E) Nov. 1884
Surtees, R., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's (E) Nov. 1884
Sutton, James, 68, Park Road, Newcastle-on-Tyne ... ... (S) Jan. 1885
Sutton, Jos., 68, Park Road, Newcastle-on-Tyne ... (E) {Graduate, Mar. 1886 / Member, Oct. 1886
Swainston, Wm., Rokeby Street, St. Mary's Road, Sunderland ... (E) Nov. 1884
Swan, H. F., North Jesmond House, Newcastle-on-Tyne ... ... (S) Nov. 1884
Swan, Thomas, 152, Ellison Street, Jarrow ... ... Nov. 1884
Swinburne, M. W., 117, Park Road, Newcastle-on-Tyne ... ... (E) Nov. 1884
Swinburne, William, 117, Park Road, Newcastle-upon-Tyne ... (E) Mar. 1886
Swinburne, T. M., Bewick Road, Gateshead ... ... (E) Jan. 1885
Swinton, A. A. Campbell, 43, Grove Street, Newcastle-upon-Tyne (E) Nov. 1884

Tate, Chas. H., 7, Side, Newcastle-on-Tyne ... ... (N A) Nov. 1884
Tatham, Stanley, Hawks, Crawshay, & Sons, Gateshead ... ... (E) Feb. 1887
Taylor, Alexander, Queen Street, Quayside, Newcastle-on-Tyne (E) Nov. 1884
Taylor, C. W., Thornewill and Warham, Burton-on-Trent ... (E) April 1885
Taylor, J. E., 13, Exchange, Plymouth ... ...(SUR) Nov. 1884
Taylor, Tom Henry, 17, Meldon Terrace, Heaton, Newcastle .. (E) Oct. 1885
Thompson, C. E., J. L. Thompson & Sons, Sunderland ... ... (S) Nov. 1884

ELECTED.

Thompson, John, Post Office Chambers, Newcastle-on-Tyne ... (E) Nov. 1884
Thompson, J. E., Thornhill Park, Sunderland ... ... (S) Nov. 1884
Thompson, J. L., Jun., North Sands, Sunderland ... ... (S) Nov. 1884
Thompson, Nicol, 32, Lawton Street, Newcastle-on-Tyne ... ... (S) Nov. 1884
Thompson, Robert, North Sands, Sunderland ... ... (S) Nov. 1884
Thompson, R. C., Messrs. Thompson & Sons, Southwick, Sunderland (S) Nov. 1884
Thompson, Charles, 9, Dean Street, Newcastle-on-Tyne ... .. (E) Feb. 1887
Thompson, Jas., 11, Elmwood Street, Sunderland ... ... (E) Dec. 1886
Thorn, W. H., 5, Waterville Terrace, North Shields ... ... (E) Nov. 1884
Tinn, Fred. D., 5, Hawthorn Terrace, South Shields ... ... (S) Nov. 1886
Todd, Surtees, Messrs. R. & W. Hawthorn, Leslie, & Co., Hebburn (S) Nov. 1884
Todd, Thomas, 20, Billiter Street, London, E.C. ... ... (E) Nov. 1885
Toomer, C. R., 26, North View, Heaton, Newcastle (E) { Graduate, May 1885 / Member, Feb. 1887
Trewent, F. J., Messrs. Swan & Hunter, Wallsend, or 9, Northumberland Terrace, Tynemouth ... ... (S) Dec. 1884
Tritton, S. B., Assistant Locomotive Superintendent, Eastern Bengal State Railway, Kanchrapara, Calcutta, India ... ... (E) Nov. 1884
Turnbull, T. W. H., 17, Monk Street, Monkwearmouth, Sunderland (E) Nov. 1884
Turner, S. J., 86, Addison Road, Heaton ... ... (E) Mar. 1887
Tweddell, R. H., 14, Delahay Street, Westminster, London, S.W. (E) Jan. 1885
Tweedy, J., Neptune Works, Low Walker ... ... (E) Nov. 1884

Ullstrom, Otto, c/o Messrs. Raylton, Dixon, & Co., Cleveland Dockyard, Middlesbro' ... ... (S) Nov. 1884
Ulm, John, Marine Casino, Pola, Austria ... ... (E) Nov. 1885

Vercoe, Jas., 3, Aubrey Place, Sunderland ... ... (SUR) Nov. 1884
Vianson, N. E., *via* Galeazzo Alessi 6 into 1, Genoa, Italy ... (E) Dec. 1885

Wailes, E. F., 8, Lombard Street, Newcastle-on-Tyne ... (SUR) Nov. 1884
Walker, Archibold, 147, Constitution Street, Leith, N.B. ... ... (E) April 1887
Walker, G., Messrs. Armstrong, Mitchell, & Co., Elswick ... ... (E) Nov. 1884
Wallau, J., Messrs. Black, Hawthorn, & Co., Gateshead ... ... (E) Nov. 1884
Walliker, J. F., 6, Lovaine Terrace, North Shields ... ... (E) Nov. 1885
Walton, F. W., Eastbourne Avenue, Walker ... ... (S) Nov. 1885
Walton, J. G., 26, Fenchurch Street, London, E.C. ... ... (E) Nov. 1884
Warburton, J., 16, Elmwood Street, Sunderland ... ... Nov. 1884
Warren, Wm., Southwick Engine Works, Sunderland ... ... (E) Nov. 1884
Watt, Adam, 11, Salem Hill, Sunderland ... ... Nov. 1884
Watts, Philip, Elswick Shipyard, Newcastle-on-Tyne ... ... (S) Nov. 1885
Waugh, G. W., Monkseaton, near Newcastle-on-Tyne ... ... (E) May 1885
Webster, R. S., Dene Cottage, Walker-on-Tyne ... ... (S) Nov. 1884
Weighton, R. L., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's (E) Nov. 1884
Weir, John, Messrs. Ramage & Ferguson, Leith ... ... (E) Nov. 1884
Welch, W. E., Brighton Grove, Newcastle-on-Tyne ... ... (S) Nov. 1884

ELECTED.

Westgarth, Tom, Westgarth, English, & Co., Middlesbro'-on-Tees (E) Oct. 1886
Westmacott, P. G. B., Elswick Works ... ... (E) Nov. 1884
West, Henry H., 14, Castle Street, Liverpool ... ... (N A) Oct. 1886
Wharrier, J., Westbourne Avenue, Walker-on-Tyne ... ... (D) Nov. 1884
White, C., 13, Mosley Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
White, R. S., Messrs. Armstrong, Mitchell, & Co., Low Walker ... (S) Nov. 1884
Whyte, Wm., Lombard Street, Newcastle-on-Tyne ... ... (E) Nov. 1884
Widdas, T. D., 99, Belgrave Street, Aigburth Road, Liverpool (SUR) April 1885
Wilis, John W., 123, Clifford Street, Byker ... ... (S) Nov. 1886
Wilkie, J., 20, Gilsland Street South, Sunderland ... ... (E) Nov. 1884
Wilkinson, J. J., 16, North Terrace, Ryton-on-Tyne ... ... (E) Nov. 1884
Willcox, F. W., 45, Sunniside West, Sunderland ... ... (E) Nov. 1884
Williams, J., 3, Azalea Terrace, Sunderland ... ... (SUR) Nov. 1884
Williams, T. R., 120, Albert Terrace, Jarrow ... ... (S) Nov. 1884
Williamson, Robt., 3, St. Nicholas' Buildings, Newcastle-on-Tyne (SUR) Nov. 1885
Willis, Jos., 78, Gosforth Street, Monkwearmouth, Sunderland ... ... Nov. 1884
Wilson, James, 100, Brougham Terrace, West Hartlepool ... ... (E) Feb. 1886
Wilson, J. T., 825, Walker Road, Newcastle-on-Tyne (E) { Graduate, April 1885 / Member, Feb. 1886
Wilson, O., 4, Pallion Road, Bishopwearmouth, Sunderland ... (E) Nov. 1884
Wilson, R. D., 17, Hawthorn Street, Newcastle-on-Tyne ... ... (E) Nov. 1886
Wilson, T., Wallsend Slipway and Engineering Co., Wallsend ... (E) Nov. 1884
Wilson, William, 29, Park Road, Newcastle-on-Tyne ... ... (S) Oct. 1885
Winstanley, P. D., Messrs. Armstrong, Mitchell, & Co., Elswick ... (E) Nov. 1884
Withy, H., Middleton Shipyard, West Hartlepool ... ... (S) Nov. 1884
Wright, R., 25, Westmorland Road, Newcastle-on-Tyne ... ... Nov. 1884

Younger, R., Victoria Villa, Heaton, Newcastle-on-Tyne ... ... (E) Nov. 1884

Zeltz, A., 48, Harrison Street, Barrow-in-Furness ... ... (E) Nov. 1884
Zimmermann, R., Villa Germania, Gaarden bei Kiel, Germany ... (S) Nov. 1884

ASSOCIATES.

Alldin, William R., Akenside Villa, Newcastle ... ... (A) Dec. 1886

Barwick, J. S., Ashbrook Grange, Sunderland ... ... (S O) Nov. 1884
Beckingham, J. H., Messrs. Scott Brothers, Dean St., Newcastle ... (S O) Nov. 1884
Boyd, Robert, Messrs. Hannay, Boyd, & Co., Quay, Newcastle ... (S O) Nov. 1884
Briggs, R. G., Moorlands, Sunderland ... ... (S O) Dec. 1886
Browne, John L., Thornhill Gardens, Sunderland ... ... (S O) Dec. 1886
Brunton, John, 3, Prior's Terrace, Tynemouth ... ... (S O) Oct. 1886

Carr, Ralph, 25, Claremont Place, Newcastle ... ... (A & S O) Nov. 1886
Coull, John, 43, Stanley Street West, North Shields ... ... (S O) Oct. 1886

		ELECTED.
Craven, John, The Cloisters, Sunderland	(R M)	Dec. 1886
Culliford, J. H. W., Sunderland	(S O)	Nov. 1884
Dunford, T. G., Messrs. Elliott, Lowrey, & Dunford, Lombard Street, Quay, Newcastle-on-Tyne	(S O)	Nov. 1884
Fisher, Jos., Messrs. Fisher, Renwick, & Co., Quay, Newcastle	(S O)	Nov. 1884
Foster, Herbert-le-Neve, Palmer's Steel Works, Jarrow	(S M)	Oct. 1886
Gjemre, Lauritz, G, King Street, Newcastle-on-Tyne	(S O)	Mar. 1886
Gracie, J. L., 53, Percy Park, Tynemouth	(S O)	Jan. 1885
Green, F. W., 14, Monk Street, Monkwearmouth	(A)	Nov. 1884
Greenwell, Thos. G., Sunderland	(S O)	Dec. 1886
Hedley, John H., 10, Esplanade West, Sunderland	(S)	Dec. 1886
Heslop, Richard O., Akenside Hill, Newcastle-on-Tyne ...	(I & S M)	Oct. 1885
Hollis, H. E., 16, Stanwick Street, Tynemouth	(I & S M)	Feb. 1885
Hudson, Ralph M., Jun., 8, The Cedars, Sunderland	(S O)	Dec. 1886
Hunting, Charles, Jesmond Dene, Newcastle-on-Tyne	(S O)	April 1886
Lowrey, E., Messrs. Elliott, Lowrey, & Dunford, Quayside, Newcastle-on-Tyne	(S O)	Nov. 1884
Maughan, William, Westmorland Road, Newcastle	(A)	Feb. 1887
McNabb, Thos., Cail's Buildings, Quayside, Newcastle	(S O)	Nov.
Milburn, J. D., Queen Street, Newcastle-on-Tyne	(S O)	Nov. 1884
Miller, T. R., c/o Messrs. Lamplough & Co., 72, Cornhill, London	(A & S O)	Nov. 1884
Mudd, John, Castletown Rolling Mills, near Sunderland ...	(I & S M)	Nov. 1884
Mulherion, G. F., Phillipson Street, Willington Quay	(A)	Nov. 1884
Newby, S., Messrs. Thomson & Newby, 13, Bridge Street, Sunderland	(I & S M)	Nov. 1884
Osbourne, Jas., Hylton, Sunderland	(S)	Jan. 1885
Patterson, John, 28, Belgrave Terrace, Newcastle-on-Tyne ...	(A)	Feb. 1885
Patterson, Thos., 6, Argyle Square, Sunderland	(S)	Jan. 1885
Pattison, W. J., Quayside, Messrs. Hunting & Pattison, Newcastle	(S O)	April 1886
Perry, Edwin, King Street, Newcastle-on-Tyne	(A)	Nov. 1885
Pinkney, D. G., Shipowner, Sunderland	(S O)	Dec. 1886
Pinkney, Thomas, Creswell Villa, Sunderland	(S O)	
Potts, E. S., 6, The Brae, Western Hill, Sunderland	(A)	Dec. 1885
Ramsay, J. W., Newburn Steel Works, Newburn	(A)	Feb. 1885
Reichwald, A., Lombard Street, Newcastle-on-Tyne	(A)	Nov. 1884

ELECTED.

Reid, Andrew, Printer, Akenside Hill, Newcastle-on-Tyne ... ... Nov. 1884
Renwick, G., Messrs. Fisher, Renwick, & Co., Newcastle-on-Tyne (S O) Nov. 1884
Roberts, G., Baltic Chambers, Quayside, Newcastle-on-Tyne ...(S O) Nov. 1884
Robson, Thos. 28, North Bridge Street, Sunderland ... ...(S O) Nov. 1884
Roche, W. M., 2, Thornhill Gardens, Sunderland ... ...(S O) Nov. 1884

Sanderson, John, 9, The Elms, Sunderland ... ...(S O) Dec. 1886
Scholefield, A., 1, St. Nicholas' Buildings, Newcastle-on-Tyne (S O) Nov. 1884
Scott, W. H., Messrs. Scott Brothers, Dean Street, Newcastle (S O) Nov. 1884
Snowball, T., Crown Buildings, Side, Newcastle-on-Tyne ...(I & S M) Nov. 1884
Snowdon, W. F., Salters Road, Gosforth ... ... (E) Dec. 1886
Speeding, James, Roker House, Sunderland ... ...(R M) Dec. 1886
Stephens, D., Messrs. Stephens, Mawson, & Co., Guildhall Chambers, Quay, Newcastle-on-Tyne, or 20, Osborne Avenue, Jesmond (S O) Nov. 1884

Taylor, John W., Thornhill Tower, Sunderland ... ...(S O) Dec. 1886
Temperley, J., Cail's Buildings, Newcastle-on-Tyne ... ...(S O) Nov. 1885
Thompson, W., Mersey Chambers, Liverpool ... ...(S O) Jan. 1886
Thompson, V. T., Baltic Chambers, Sunderland ... ...(S O) Dec. 1886

Varley, John, 131, High Park Road, Leeds ... ... (I & S M) Mar. 1887

Wait, James, Maritime Buildings, Quay, Newcastle-on-Tyne ...(S O) Nov. 1884
Ward, Joseph, Wallsend Slipway Co., Wallsend-on-Tyne ... ... (A) Nov. 1886

GRADUATES.

Anderson, Robert, 21, Picton Place, Newcastle ... ... Nov. 1886
Andlaw, W. F., 13, Russell Street, North Shields .. .. Dec. 1884
Armstrong, Walter, 36, Suffolk Street, Bishopwearmouth, Sunderland ... Dec. 1885
Armstrong, William, 63, Croft Terrace, Jarrow ... ... Oct. 1886

Barnes, William, 6, Elmwood Street, Sunderland ... ... Feb. 1887
Blackett, Walter, 6, Windsor Crescent, Newcastle ... ... Nov. 1886
Blackmore, H., 21, Picton Place, Newcastle ... ... Oct. 1886
Brackenbury, H. J., 2, Campbell Street, Newcastle ... ... Mar. 1887
Bramwell, Balfour, 20, Beverley Terrace, Cullercoats ... ... Nov. 1886
Burton, C. D., 34, Edith Street, Jarrow ... ... Oct. 1886

Carpenter, F., 22, De Grey Street, Newcastle-on-Tyne ... ... May 1885
Chisholm, 30, Clyde Street, Jarrow ... ... Dec. 1886
Collyer, P. N., Hurworth-on-Tees, Darlington ... ... Mar. 1886
Common, F., 13, Tavistock Place, Sunderland ... ... May 1885
Cooper, C. R., Palmer's Engine Works, Jarrow-on-Tyne ... ... Oct. 1886
Cornish, H. P. ... ... Nov. 1884

ELECTED.

Coull, Alex. B., 43, Stanley Street W., North Shields ... ... Feb. 1887
Crosby, J., 1, Randolph Street, Sunderland ... ... May 1885
Curwen, Henry R., Schiffs bau werft, "Germania," Gaarden bei Kiel, Germany ... ... Feb. 1886

Dainton, Charles Hopton, 22, Tatham Street, Sunderland ... ... Mar. 1886
Davie, Albert, 75, Mount Pleasant, Barrow-in-Furness ... ... Feb. 1886
D'Eyncourt, Eustace, 2, Hawthorn Terrace, Newcastle ... ... Dec. 1886

Elder, Edward, 18, Prospect Terrace, Jarrow-on-Tyne ... ... April 1886

Fairbairn, Jas., 49, Harrogate Street, Sunderland ... ... May 1885
Fawcett, J., 8, Canada Street, Shieldfield, Newcastle-on-Tyne ... ... Jan. 1886
French, James, 7, Avenue, Wallsend-on-Tyne ... ... Mar. 1887

Gayner, Robert H., Beech Holm, Sunderland ... ... Mar. 1886
Graham, William, 30, Hill Street, Jarrow ... ... Feb. 1886

Head, A. P., 20, Elswick Row, Newcastle ... ... Nov. 1884
Henshall, Samuel, 9, Chester Road, Sunderland ... ... May 1885
Holey, J. T., 19, Rosslyn Terrace, Sunderland ... ... Jan. 1886
Horner, J., Springwell House, South Street, Sunderland ... ... May 1885

Macindo, John, 11, St. Bede's Terrace, Sunderland ... ... Nov. 1885
Maddison, G. D., 9, Salem Avenue, Sunderland ... ... May 1885
Maling, Frank A., 2, Toward Terrace, Sunderland ... ... Dec. 1885
Marshall, F. T., 38, Percy Gardens, Tynemouth ... ... Jan. 1885
Metcalf, Thos., 6, Dundas Street, Sunderland ... ... May 1885
Miller, T. B., 6, Vernon Terrace, Gateshead ... ... Nov. 1886
Milne, T., 41, Addison Street, Sunderland ... ... May 1885
Muir, A. E., 96, Roker Avenue East, Sunderland ... ... May 1885
Munro, Alex., 20, Linskill Terrace, North Shields ... ... Nov. 1886
Munro, Henry J., 47, King Street, North Shields ... ... Nov. 1886

Nicholson, John, Messrs. Black, Hawthorn, & Co., Gateshead ... ... Dec. 1886
Nicolson, Gilbert C., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's, Newcastle-on-Tyne ... ... Oct. 1885
Noble, Robert, 13, Prospect Terrace, Jarrow-on-Tyne ... ... Nov. 1886

Plummer, M. S., Rose Hill, Low Fell, Gateshead ... ... Nov. 1885

Ramshaw, G. H., 31, Barclay Street, Sunderland ... ... May 1885
Reavell, Wm., 20, Falconar Street, Newcastle ... ... April 1885
Rickaby, Augustine, Bloomfield Engine Works, Monkwearmouth, Sunderland ... ... Nov. 1885
Roberts, T. C., Neptune Shipyard, Low Walker ... ... Oct. 1886

	ELECTED.
Robinson, Wm., 6, Choppington Street, Newcastle-on-Tyne	May 1885
Ross, A. T. C., 19, East Parade, Newcastle	Dec. 1886
Rutherford, J. T., 7, Marlbro' Crescent, Newcastle-on-Tyne	Jan. 1886
Scott, H., 47, Mainsforth Terrace, Sunderland	May 1885
Shaw, Thomas, West Boldon, near Sunderland	Dec. 1885
Skinner, Leslie, 22, Ravensbourne Terrace, South Shields	Dec. 1886
Sowerby, William, 67, North Street, Jarrow	Feb. 1886
Speeding, Joseph C., Roker House, Sunderland	Dec. 1886
Spencer, P. G., 3, Victoria Street, Newcastle-on-Tyne	May 1885
Stoddart, Swinton, 24, North Milburn Street, Sunderland	May 1885
Thompson, Luke, 13, Chester Road, Sunderland	Jan. 1886
Tone, J. M. F., 50, Clayton Park Square, Newcastle-on-Tyne	April 1885
Towers, Edward, Jun., 4, Latimer Street, Tynemouth	Nov. 1886
Wardle, Wm., 1, Buxton Terrace, Sunderland	May 1885
Watson, A. R.	May 1885
Watson, R. J., 8, Northumberland Villas, Wallsend	Jan. 1886
Weatherall, J., 264, Wansbeck Terrace, Shields Road, Heaton	Oct. 1885
Westmacott, Alfred, Benwell Hill, Newcastle-on-Tyne	Dec. 1885
Wheeler, O., 4, Wilberforce Street, Wallsend	Oct. 1886
Wilson, R., 8, The Green, Bishopwearmouth, Sunderland	Jan. 1886
Wood, Henry A., Longlands, Middlesbro'	Oct. 1886
Wortley, H., 11, Burton Street, Byker, Newcastle-on-Tyne	Jan. 1886

THE LATE MR. IVAN MAVOR.

On the evening of Sunday, Dec. 26th, 1886, on board the steamship "Petriana," which was lying in Clover's Dock, Birkenhead, Ivan Mavor met his death by an explosion of petroleum vapour or spray. The story of this sad accident, by which ten men lost their lives, was told with sufficient fulness in the newspapers of the day, and does not require further reference here.

Mr. Mavor was a young man of such exceptional promise that his untimely end deserves more than a mere passing notice.

Ivan Mavor was the son of the Rev. James Mavor, of Pollokshields, Glasgow. He was educated at the Glasgow High School, and very early in life evinced a decided bent for the business of a shipbuilder. This led to his being apprenticed with Messrs. John Elder and Co., Fairfield, with which firm he acquired his first knowledge of shipbuilding in all its branches. After completing his apprenticeship he was for two years in the drawing office of Messrs. A. & J. Inglis, Pointhouse Shipyard. He then transferred the scene of his labours to the Tyne, where, as draughtsman with Sir W. G. Armstrong, at Elswick, and subsequently as assistant manager with the amalgamated firms of Messrs. Armstrong, Mitchell, & Co., Limited, Low Walker, he quickly rose into notice as a young man of rare talent. In the beginning of the year 1886 he was appointed manager in the shipbuilding department of Messrs. R. & W. Hawthorn, Leslie, & Co., Limited, Hebburn, and this post he held up to the date of his death. He was 26 years of age.

Such, briefly told, is the equally brief professional career of Ivan Mavor. To have attained to such a position as that which he held at the very early age of 26 years augurs his possession of no common acquirements. Endowed by nature with a fine physical constitution, a clear brain, and an indomitable will, he applied himself unsparingly and incessantly to the acquisition of the principles and the practice of the business of his choice. Only those who knew him most intimately were aware of the self-denial he persistently imposed upon himself. With all the more intricate problems of the science of naval architecture he was fully conversant. Nothing pleased him better than to have some knotty

point in the question of steamship efficiency or steamship propulsion to elucidate. In the application of his theoretical knowledge to the practical art of the shipbuilder he was ever enthusiastic, and it was in this sphere that those of his friends who knew him best predicted for him his greatest success.

He was a member of the Council of our Institution from its commencement, and in its proceedings he took a lively interest and an active part. In 1885 he contributed—in conjunction with Mr. T. Millar—a paper "On some Considerations regarding the Freeboard of Merchant Ships," and at the date of his death he had barely finished writing another paper on the "Education of Engineers and Shipbuilders," which he intended to have read before us in January, 1887. This latter paper was taken as read, and is published in the present volume.

He was married only three weeks previous to the date of his death.

R. L. W.

THE LATE MR. W. J. CLARK.

MR. W. J. CLARK was born at Hylton, near Sunderland, in December, 1847, and was the second son of the late Mr. George Clark, of the Southwick Marine Engine Works, Sunderland. He commenced his education at private schools, and at an early age showed marked ability in his studies. Having passed with honours in the public examinations at the University of Durham, he entered the engine works of his father, to serve his apprenticeship. He then went to St. John's College, Cambridge, took high honours, and finally obtained the degree of M.A. After travelling for a short time on the Continent, he again joined the Southwick Engine Works, and up to the time of his death assisted his brothers in the management of that extensive business.

For three years previous to his decease he had not enjoyed good health, but it was only in the early part of last year that his illness was thought to be of a serious nature, and he proceeded to London to obtain the advice of the most eminent physicians. After a temporary residence at Bournemouth, he had so far recovered as to be able to return to Sunderland. In the course of a month or two he again left for London, with the intention of proceeding to the South of France, but his constitution was so weakened that he was obliged to remain in London, and, after a severe attack of paralysis, died at the Hotel Metrôpole on the third of February, 1887.

He was a Justice of the Peace for the Borough of Sunderland; and as a member of the Council of the North-East Coast Institution of Engineers and Shipbuilders, took an active interest in all its proceedings.

He was of a very genial disposition, and most generous. Being a great authority on mathematics and theoretical science in connection with every kind of engineering, he was often consulted upon difficult questions; many technical works contain much valuable information contributed by him, and it is not too much to say that by his death the North-East Coast has suffered a loss in engineering talent.

H. H. W.

THE LATE MR. JOHN BROCKAT.

Mr. John Brockat was born in Glasgow in the year 1835, and was the fourth son of the late Mr. Andrew Brockat, builder, etc., of that city. His career was a varied and interesting one, embracing a large practical experience which few could equal. His earlier years were spent in some of the largest marine engineering establishments on the Clyde, at that time the great centre of this important industry. After the completion of his apprenticeship, and for the first nine years of his professional life, he was in the service of Messrs. Randolph and Elder, where he worked both as a mechanic and draughtsman. He then joined the firm of Messrs. Simons & Co., of Renfrew, and afterwards became head draughtsman to Messrs. Barclay & Co. On leaving them he took the superintendence of the Cork Steamship Co.'s fleet, and subsequently held the position of outside manager, first for the firm of Messrs. A. J. Inglis & Co., and secondly for Messrs. Elder & Co. In 1871 he proceeded to China to take the management of the Hong Kong and Whampoa Dock Company. In the latter part of 1876 he returned to England, was shortly afterwards appointed surveyor to Lloyd's Register of Shipping, and at the time of his death held the position of principal engineer-surveyor to that society for the Tyne Ports. He died on February 26th, 1887, after a short illness of thirteen days, and was interred in Glasgow. He was a member of the Institution of Naval Architects and a member of the Council of this Institution, in the proceedings of which he took a lively interest. Being very widely known and respected both in his official and private life, his kind and genial disposition, combined with an unostentatious manner, always won for him the goodwill of all.

J. F. W.

THE NORTH-EAST COAST INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS.

Constitution and Bye-Laws,

ADOPTED AT A GENERAL MEETING ON THE 4th MARCH, 1885.

REVISED AT THE CLOSING BUSINESS MEETING HELD ON MAY 4TH, 1887.

CONSTITUTION.

I.—The NAME of the Association is "The North-East Coast Institution of Engineers and Shipbuilders." Name

II.—The OBJECTS for which the Institution is established are:—The advancement of the science and practice of Engineering and Shipbuilding, and the interchange of ideas and information amongst its members, by means of meetings for the reading and discussion of papers relating thereto, and placing on record its transactions. Objects

III.—The Institution shall consist of Honorary Members, Members, Associates, and Graduates.

IV.—HONORARY MEMBERS shall be such distinguished persons as the Council may elect. Honorary Members.

V.—MEMBERS shall be Principals or Principal Managers engaged in Engineering or Shipbuilding; Civil, Military, or Mining Engineers, or Naval Architects; whose subscription shall be Two Guineas per annum: and other persons engaged in the above professions; whose subscription shall be Half-a-Guinea per annum. Members.

VI.—ASSOCIATES shall be such persons as are not strictly Engineers or Shipbuilders, but are connected with or interested in such pursuits, and are deemed by the Council to be eligible for Associate membership. Their subscription shall be One Guinea per annum. Associates

Graduates.

VII.—GRADUATES shall be persons under twenty-one years of age, engaged in study or employment to qualify themselves for any of the above professions. Their subscription shall be Five Shillings per annum.

Life Members and Associates.

VIII.—Any MEMBER may become a LIFE MEMBER by a single payment of Twenty Guineas, or any ASSOCIATE may become a LIFE ASSOCIATE by a single payment of Ten Guineas.

Officers.

IX.—The OFFICERS of the Institution shall be elected from and by the Members, and shall consist of one President, the Past-Presidents, six Vice-Presidents, fifteen Councilmen, and an Honorary Treasurer.

Election of Officers (See Bye-Law No. 11.)

X.—The President and Honorary Treasurer shall be elected annually. Two Vice-Presidents and five Councilmen shall be elected annually. The retiring Vice-Presidents and Councilmen shall, at the end of the first year, be decided by ballot from the whole number; at the end of the second year, by ballot from the number who have served two years; and each succeeding year they shall be those who have served three years from their last election.

The President shall be eligible for re-election for a second year; should he be re-elected he shall retire at the conclusion of his second year of office, and shall not again be eligible until after an interval of one year.

The retiring Vice-Presidents and Councilmen shall not be eligible for re-election to the same offices until after a similar interval, but shall be eligible for election to any other office.

The Honorary Treasurer shall be eligible for re-election annually, or for election to any other office.

Honorary Members' Privileges.

XI.—Honorary Members may attend all the General Meetings, they may read papers, take part in discussions, in voting, in moving and supporting resolutions, in presentation of notices of motion, or in requisitions for Special Meetings, and in the proposition of new members; they shall also receive copies of the Transactions.

Members Privileges

XII.—Members shall have all the privileges of the Institution, as enumerated in the foregoing paragraph, and shall be eligible for office.

XIII.—Associates shall have all the privileges enumerated in paragraph XI. They shall be eligible for office as Councilmen. Associates' Privileges.

XIV.—Graduates may attend all the General Meetings, they may read papers, take part in discussions, and support resolutions; they shall also receive copies of the Transactions, but shall not sign proposals for new members, vote, nor be eligible for office. Graduates' Privileges.

XV.—The General Meetings of the Institution shall be held during the winter seasons of each year. General Meetings.

NOTE.—When the word Member is initialled with a capital letter it signifies a member under paragraphs IV. and V., but when initialled with a small letter, it signifies a member of any class of the Institution membership.

BYE-LAWS.

Revised at the Closing Business Meeting held on May 4th, 1887.

MEMBERSHIP.

1.—Every candidate for admission as a Member, Associate, or Graduate shall be proposed and recommended according to the form A in the Appendix, in which form the name, usual residence or the place of business, the qualification for, and proposed class of membership of the candidate shall be distinctly specified. Proposals for Graduates must give the date of, and age, last birthday. Candidates for Admission.

The form shall be signed by a Member or Associate of the Institution, as proposer, and by at least other three Members or Associates as supporters, certifying a personal knowledge of the candidate.

The proposal so made shall be submitted to the Council, when, if it be approved, the Chairman shall sign the approbation, which shall be inserted in the notice calling the next General Meeting, when the candidate shall be balloted for, and shall be accepted if three-fourths of the votes are favourable.

2.—Graduates desirous of becoming Members shall be proposed and recommended according to the Form B in the Appendix. Graduates becoming Members.

The proposal so made shall be submitted to the Council, who shall agree to or reject it.

Balloting for Members.

3.—The balloting for membership shall be conducted in the following manner:—Each member shall be supplied by post with a list of the names of the candidates, according to the Form C in the Appendix, and shall strike out the names of such candidates as he desires shall not be elected. These lists may be returned to the Secretary by post, or may be deposited in the ballot-box by the voter in person on entering a meeting at which an election is to take place. The ballot-box will be closed at ten minutes after the advertised time of meeting. The lists shall then be handed over to the Chairman, who shall appoint two Scrutineers to examine them, after which examination the Chairman shall inform the meeting of the result.

Candidates to receive Notice of Election.

4.—Notice of Election as a member shall be sent to the candidate within one week after his election, according to the Form D in the Appendix; but his name shall not be added to the list of Members, Associates, or Graduates of the Institution, until he shall have paid his first annual subscription.

Rejection of Candidates.

5.—In case of rejection of the candidate, no mention thereof shall be made in the minutes, nor shall any notice be given to the unsuccessful candidate.

Subscriptions payable in Advance.

6.—All subscriptions shall be payable in advance, and shall become due on the 1st of June each year. Any member withdrawing from the Institution after that date is still liable for the amount of subscription due on that day. Application for membership may be made at any time during a Session, and the subscription shall cover the membership up to the 1st of June following.

Receipt of Subscription

7.—On payment of each subscription the Secretary shall forward to the member an official receipt.

Questions of Privilege.

8.—On question of privilege.—Any person who may be unknown in the meeting shall only be able to claim the privilege in question on proving his membership for the current Session.

Arrears of Subscriptions.

9.—Any member whose subscription is one year in arrear shall be reported to the Council, who shall direct application to be made for it, according to Form E in the Appendix; and in the event of its continuing in arrear until the end of that

Session after such application, the Council shall have the power, after remonstrance by letter, according to the Form F in the Appendix, of declaring that the defaulter has ceased to be a member.

Power of Council to remove Name from List of members.

10.—The Council may refuse to continue to receive the subscriptions of any member who shall have wittingly acted in contravention of the Regulations of the Institution, or who shall, in the opinion of the Council, have been guilty of such conduct as shall have rendered him unfit to continue his membership; and the Council may remove his name from the list of members: and such person shall thereupon cease to be a member of the Institution. Notice of such action of the Council shall be forwarded to the person in question, in accordance with the Form G in the Appendix. The reason for such action of the Council shall not be stated to the person expelled, without the sanction of the Council.

OFFICERS.

Election of Officers.

11.—The Annual Election of Officers shall be conducted in the following manner:—The Council shall meet in March or April, and shall arrange a list of nominations, in accordance with the Form H in the Appendix. Such list shall be presented at the General Meeting immediately preceding the last General Meeting of the Session, and any Member present shall be at liberty to nominate additional Members. The list shall show who remain in office throughout the Council, and who are retiring. It shall nominate new names in the place of the retiring Members, and the number of nominations shall be, at least, two in excess of the number required in each section of the Council. A copy of this ballot list shall be forwarded to each Member and Associate, together with a complete list of Members, to be filled in, in accordance with the instructions printed in the ballot form, and to be returned to the Secretary, to be opened in the presence of the Council, at a Council Meeting which shall be held in April or May, when the scrutiny and counting shall be carried out by the Council. Any Member in voting shall be at liberty to erase any name or names from the

list and substitute the names of any other person or persons eligible for each respective office other than those already placed on the ballot list by the Council and Members of the Institution.

Any voting paper returning either more or less than one President, six Vice-Presidents, one Honorary Treasurer, and fifteen Councilmen, shall be disqualified for the section or sections in which such errors occur, and the votes shall be lost for the said section or sections. The votes given as President, to a Member who is not elected President, shall count to him as a Vice-President; the votes given as Vice-President, or Treasurer, to persons not so elected, shall count to them as Councilmen, unless they have just completed a term of office in such capacity.

The voting list shall not be sent to any Member and Associate whose subscriptions are more than one year in arrear; nor shall any Member be nominated on the list. For this purpose, the Secretary shall prepare, previously to the meeting of Council, a list of those Members whose subscriptions are more than one year in arrears.

Ballot to be declared at May Meeting.

12.—The result of the ballot for Officers shall be declared at the General Meeting, to be held in May, at which meeting general business shall be transacted. At the May General Meeting the newly-elected Officers, after being declared, shall enter into office; and this shall be the last meeting of the Session.

Power of Council to fill up Casual Vacancy.

13.—The Council shall have power to supply any casual vacancy within itself (including any casual vacancy in the office of President), which shall occur between one May Meeting and another; and the Officers so appointed shall retire when the person whose place they fill would have retired. Vacancies not filled up during the year shall be filled at the General Election.

GENERAL MEETINGS.

General Meetings.

14.—The Annual General Meeting shall take place in October, and shall be held in Newcastle. The Ordinary Meetings shall take place in the second week in each following month during the Session, unless otherwise arranged by the Council, and at such hours and places as the Council may determine.

Notice of Meetings.

15.—Seven clear days' notice of every General Meeting, Ordinary or Special, specifying the nature of business to be transacted, shall be given to every member of the Institution.

Special General Meetings.

16.—A Special General Meeting may be convened at any time by the Council, and such meeting shall be convened by the Council whenever such is the declared wish of a General Meeting, or whenever a written requisition, signed by twenty members, specifying the object of the meeting, is left with the Secretary. If, for fourteen days after the delivery of such requisition, a meeting be not convened in accordance therewith, the requisitionists, or any twenty members of the Institution, may convene a Special Meeting in accordance with the requisition. The business discussed at such Special Meetings shall only be that indicated on the notice calling the meeting.

Quorum.

17.—Twenty Members shall constitute a quorum for the purpose of a meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purpose of a Special meeting.

Chairman at Meetings.

18.—The President shall be chairman at every meeting, and in his absence, one of the Past-Presidents or one of the Vice-Presidents; or in the absence of these, a Councilman shall take the chair; or if no Councilman be present and willing to take the chair, the meeting shall elect a Chairman.

Decisions of General Meetings.

19.—The decision of a General Meeting shall be ascertained by a show of hands; or, when five Members or Associates shall demand, or the Chairman may think it desirable, the decision shall be taken by ballot. The manner of counting the votes shall be at the discretion of the Chairman, and an entry in the minutes, signed by the Chairman, shall be deemed sufficient evidence of the decision of a General Meeting. In cases of equality of votes, the Chairman shall have a casting vote; otherwise he shall not vote.

Questions of a Personal Nature in General Meetings.

20.—Questions of a personal nature arising in a General Meeting, shall, if possible, be referred to the Council, otherwise the decision of the meeting shall be taken by ballot on a motion or amendment put to the meeting. The ballot shall be taken by the voters (being Members or Associates) writing "for" and "against" on a slip of paper. The slips shall be folded and

collected, and then counted in the presence of the meeting, and the result announced by the Chairman. Should fewer than twenty votes be given, it shall be understood that the question is shelved, and the votes shall be destroyed without being opened.

Transactions of Business General Meetings.

21.—At every General Meeting of the Institution, the Secretary shall first read the minutes of the preceding meeting, which, on approval, shall be signed by the Chairman; business arising out of these minutes shall then be transacted. The Secretary shall read any notices which may have to be brought before the meeting. Notices of motion may then be given, and other business of the Institution may be attended to; but when a paper is to be read, the foregoing business shall not be extended beyond half-an-hour after the advertised time for commencing the meeting. The paper or papers for the evening shall then be read and discussed.

Dissolving a General Meeting.

22.—If within half-an-hour after the time fixed for holding a General Meeting a quorum is not present, the meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at the meeting so dissolved, may forthwith be done on behalf of the meeting, by the Council; except the reading or discussion of a paper, which shall not proceed in the absence of a quorum.

Adjourning a General Meeting.

23.—Any General Meeting of the Institution may be adjourned by a vote of the Members and Associates present if there be a quorum; if there be not a quorum, the case shall be met by the preceding paragraph.

Introduction of Friends.

24.—Each member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book, together with that of the member introducing him; but if the introducing member be unable to attend the meeting, he may send the name of the visitor to the Secretary. During such portions of any of these meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw. This shall be done if five Members or Associates, or both, present request it.

COUNCIL MEETINGS.

Council Meetings.

25.—The Council shall meet before each General Meeting, or on other occasions when the President shall deem it necessary; being summoned in either case by circular, stating the time of meeting, and the business, so far as is known.

Convening Meeting for Expenditure of Funds.

No business involving expenditure of the funds of the Institution (except by way of payment of current accounts) shall be transacted at any Council Meeting, unless the circular gives six clear days' notice, and states the business.

Discussions of a Personal Character.

All discussions of a personal character in the Council shall be considered and treated as being strictly confidential.

Regulation of Proceedings.

26.—The Council may regulate its own procedure, and delegate any of its powers and discretions to any one or more of its number.

Chairman and Quorum.

The President shall, *ex-officio*, be chairman of all Council Meetings, and in his absence one of the Past-Presidents or one of the Vice-Presidents shall take the chair; or in the absence of these, one of the Councilmen shall be elected to take the chair. Five members of Council, including the Chairman, shall form a quorum.

Sub-Committees.

In the appointment of Sub-Committees, the Council shall determine the number which shall form a quorum in each case, and shall appoint a Chairman. These regulations shall not affect the Finance Committee.

Sub-Committees.

27.—The Council may appoint Committees either from itself, or with the assistance of persons outside, for the purpose of transacting any special business, or of investigating specific objects connected with the work and interests of the Institution.

Sub-Committees.

28.—All Committees or Sub-Committees shall be appointed by the Council, and shall be subject to that body, and shall report to it. The Council shall act upon these reports or recommendations as it may think best.

Invitation of Strangers.

29.—The Council may invite to General Meetings or to Council Meetings any person or persons whose presence and assistance it may desire, and strangers so invited shall be permitted to take part in the proceedings, but not to vote.

Secretary and Treasurer's Duties.

30.—The Secretary, who shall also act as Treasurer, shall be appointed by and act under the direction and control of the Council, and shall be paid such salary as the Council shall determine. He shall attend all meetings, Council and General, and shall take minutes of the proceedings, and enter them in proper books provided for the purpose. He shall write the correspondence of the Institution and Council, read minutes and notices at meetings, report discussions, and, if required by the Council, prepare papers for reading and publication, and read papers and communications at the meetings. He shall receive all payments due to the Institution, and shall bank the cash in hand whenever it amounts to ten pounds. The bank shall be determined by the Council and the banking account shall be in the names indicated in connection with the Finance Committee. He shall keep a cash account book, general and detail, which shall on all occasions be open to inspection by the Finance Committee or by the Council. He shall keep a register of the names of members, so arranged as to distinguish all members whose subscriptions are in arrear. He shall also perform whatever other duties are indicated in the Bye-Laws of the Institution as appertaining to his department; and shall remain in office during the pleasure of the Council. He shall not vote on any resolution.

Finance Committee.

31.—The following Sub-Committees shall be appointed annually by the Council :—(1) A Finance Committee, to consist of seven persons, viz., one Vice-President, who shall be Chairman; five Councilmen, and the Honorary Treasurer of the Institution; three of whom shall form a quorum. The Treasurer shall be empowered to pay all amounts due from the Institution which are under two pounds. All amounts of two pounds and upwards shall be paid by cheque signed by the Chairman of the Finance Committee (or in his absence, by the President or a Past-President), the Secretary, and the Treasurer. (2) A Reading Committee, to consist of six members of Council.

Payment of Accounts.

Reading Committee.

TRANSACTIONS.

Papers to be submitted to Council.

32.—All papers shall be forwarded to the Secretary at least five clear weeks before the proposed date of reading. The Secretary shall submit them for approval to the Council, and on their general approval they shall be handed to the Reading Sub-Committee, three of whom at least, shall read the paper through. The Reading Committee shall be at liberty to strike out any parts which, in their opinion, ought not to be read. They may also make any suggestions to the author as to points which might with advantage be inserted or altered.

Reading Committee.

Printing Transactions.

33.—The papers read, and the discussions on them, or such portions of them as the Council shall select, shall be printed for distribution among the members, each of whom shall receive a copy. These Transactions shall be edited by the Secretary, in accordance with instructions of the Council, who shall have power to omit parts of discussion which may be foreign to the subject, or which it may be deemed undesirable to retain. Each paper shall bear the date on which it was read in General Meeting.

Copy of Papers supplied to members before reading, etc.

34.—Copies of papers to be read during any session will be sent seven days before the date of reading to members who shall have applied to the Secretary for them, in writing, at the commencement of the session. The discussion on a paper shall not be considered closed on the evening on which it is read, but shall be open for renewal at a subsequent meeting, prior to the reading of the paper set down for that date.

Proofs sent to members for Correction.

35.—Proofs of the reports of discussions shall be sent for correction to the members who have taken part in the discussion, but must be returned to the Secretary within seven days of the date on which they were sent, otherwise they will be deemed correct, and will be printed off.

Liberty to Print Explanatory Notes.

36.—The Council shall be at liberty to print as Transactions, either with the papers and discussions or separately, explanatory notes, etc., communicated after the reading or discussing of a paper. Such communications shall bear the date on which they shall have been received by the Secretary.

Institution not responsible for statements.

37.—The Institution shall not be held responsible for the

statements and opinions advanced in any of the papers which may be read, or in the discussions which may take place at the Meetings of the Institution.

Copies of Transactions to be sent to members.

38.—Twenty copies of each paper and discussion shall be presented to the author of the paper, for private use, and one copy shall be sent to each member. When a paper is prepared by two authors, fifteen copies shall be presented to each. Duplicate copies of parts of the Transactions mislaid or lost by members cannot be supplied to them, except as provided for in Bye-Law 41.

Transactions not supplied to Members in Arrears.

39.—The Transactions shall not be supplied free to members whose subscriptions are more than one year in arrear.

Members not to receive Transactions till after First Payment.

40.—Any member elected at any time between the Annual General Meetings shall be entitled to copies of all the Transactions issued during the session to which his first subscription applies; but not until the subscription has been paid.

Transactions the Property of the Institution.

41.—The Transactions of the Institution shall be the exclusive property of the Institution, and shall be published only by the authority of the Council. Additional copies of papers required by authors for their private use can only be procured from the Secretary, at prices fixed by the Council from time to time, and these copies must contain the whole of the discussion following the papers, and be bound in the usual cover, with the addition of the following words:—"By permission of the Council," and "Excerpt Minutes of Proceedings." Duplicate volumes and copies of parts of the Transactions, if in print, can also be obtained from the Secretary, and shall be sold only by him, in such manner and at such prices as the Council shall have fixed.

Rule of Discussion.

42.—During a discussion upon any paper, no person shall be at liberty to speak more than once (except by way of explanation), nor for a longer period than ten minutes.

ACCOUNTS.

43.—The Council shall present the yearly accounts (up to the 31st of May preceding) at the October General Meeting of

each year, after they have been audited by a professional Accountant, appointed by the members at the General Meeting in May.

ALTERATIONS TO CONSTITUTION AND BYE-LAWS.

44 —Alteration in or addition to the Constitution and Bye-Laws may be made only by resolution of the members at the May General Meeting, after notice of the proposed alteration or addition has been announced at the previous General Meeting.

The resolution may be modified by the Council meanwhile, should they so desire ; but in this case it shall be read at the May General Meeting in its original form before it is proposed in the amended form.

Such resolutions shall be stated in the notice calling the intervening Council Meeting, and also in the notice calling the May General Meeting.

Any member unable to be present at the meeting at which such alterations are to be considered, but who is nevertheless desirous of recording his opinion thereon, shall be allowed to vote by proxy, such proxies shall be in Form J in the Appendix, which may be had on application to the Secretary, and may be used by any member present at the meeting on behalf of the absent member, and counted by the Chairman as of equal value with votes given in the manner provided in Bye-Law 19.

APPENDIX.

FORM A. (BYE-LAW 1.)

A. B. [Christian Name, Surname, Occupation, and Address in full] being desirous of admission into the North-East Coast Institution of Engineers and Shipbuilders, we, the undersigned [Members or Associates], propose and recommend that he shall become [a Member, Associate, or Graduate] thereof. We know him to be [a Principal, &c., or engaged in, &c.,] and eligible for the proposed membership.

FROM PERSONAL KNOWLEDGE.

Signed_____
_____
_____
_____
} Four [Members or Associates.]

Dated this day of 18

FORM B. (BYE-LAW 2.)

A. B. [Christian Name, Surname, Occupation, and Address in full] being at present a of the North-East Coast Institution of Engineers and Shipbuilders, and upwards of twenty-one years of age, and being desirous of becoming a of the said Institute, we, the undersigned [Members or Associates], recommend him, from *personal knowledge*, as a person eligible for the proposed Change of membership, because—

(*Here specify distinctly the Qualifications of the Candidate according to the spirit of the Rules of the Institution.*)

Signed_____
_____
_____
} Three [Members or Associates.]

Dated this day of 18

FORM C. (BYE-LAW 3.)

BALLOTING PAPER FOR MEMBERSHIP.

The Council having considered the recommendations for Membership of the following gentlemen, present them to be balloted for, viz.:—

Member, Associate or Graduate.	Address.	Nominated by.	Supported by.

Strike out the names of such persons as you desire shall *not* be elected, and forward the list by post to the Secretary, or personally place it in the ballot-box at the Meeting.

FORM D. (BYE-LAW 4.)

Sir,—I am directed to inform you that on the day of you were elected a of the North-East Coast Institution of Engineers and Shipbuilders, but, in conformity with Bye-Law 4, your election cannot be confirmed, nor your name be added to the roll of membership, until you have paid your first annual subscription, the amount of which is £ : : , or, at your option, the Life Composition of £ : : .

Payment may be made to the Treasurer, Mr._____

Address_____

I am, Sir,

Yours faithfully,

Secretary.

Dated 18

N.B.—In case of a Graduate, strike out "*or, at your option, the Life Composition of £ : : .*"

FORM E. (BYE-LAW 9.)

SIR,—I am directed by the Council of the North-East Coast Institution of Engineers and Shipbuilders to draw your attention to Bye-Law 6, and to remind you that the sum of £ of your annual subscriptions remains unpaid, and that you are in consequence in arrear of subscription.

I am also directed to request that you will cause the same to be paid without further delay, otherwise the Council will be under the necessity of exercising their discretion as to using the power vested in them by the Rule above referred to.

I am, Sir,

Yours faithfully,

Secretary.

FORM F. (BYE-LAW 9.)

SIR,—I am directed by the Council of the North-East Coast Institution of Engineers and Shipbuilders to inform you that in consequence of non-payment of your arrears of subscription, and in pursuance of Bye-Law 9, the Council have determined that unless payment of the amount (£) is made previous to the day of next, they will proceed to declare that you have ceased to be a member of the Institution.

But, notwithstanding this declaration, you will remain liable for payment of the arrears due from you.

I am, Sir,

Yours faithfully,

Secretary.

FORM G. (BYE-LAW 10.)

SIR,—I am directed by the Council of the North-East Coast Institution of Engineers and Shipbuilders to inform you that they feel it their duty to advise you to withdraw from the Institution, or otherwise they will be obliged to act in accordance with Bye-Law 9 (or 10, as the case may be.)

I am, Sir,

Yours faithfully,

Secretary.

FORM H. (BYE-LAW 11.)

BALLOTING LIST.

PRESIDENT.—ONE NAME only to be returned, or the vote will be lost.

——— President for the current year (eligible for re-election.)*

———
———
——— } New Nominations, from whom to select ONE.

VICE-PRESIDENTS.—SIX NAMES only to be returned (including the four who remain in office), or the vote will be lost.

———
———
———
——— } Four Vice-Presidents remaining in office, whose seats are NOT vacant.

———
——— } Two Vice-Presidents retiring, and NOT eligible for re-election.

———
———
———
——— } New Nominations, from whom to select TWO names.

TREASURER.—ONE NAME only to be returned, or the vote will be lost.

——— Treasurer for the current year, eligible for re-election.

———
———
——— } New Nominations, from whom to select ONE.

COUNCILMEN.—FIFTEEN NAMES only to be returned, including the ten who remain in office.

———
———
———
———
———
———
———
———
———
——— } Ten Councilmen remaining in office. These do not require to be voted for at this election, as their term of service has NOT yet expired.

———
———
———
———
——— } Five Councilmen retiring, and NOT eligible for re-election.

———
———
———
———
———
———
——— } New Nominations from whom to select FIVE.

* To be crossed out before issue, when the President is not eligible for re-election

N.B.—(*a*) The names of those who remain in office will be counted in the total number required without being re-written by the voter.

(*b*) Any list having either MORE or LESS than the required number of names voted for in any section will be disqualified for that section.

(*c*) Votes as President for a person who is not elected will count for him as a Vice-President.

(*d*) Votes as Vice-President, or Treasurer, for persons not so elected, will count for them as Councilmen, unless they have just completed a term of office in that capacity.

(*e*) This list, duly filled in, may be returned to the Secretary by post, or handed to him, so as to be on the Council table before the commencement of the scrutiny, which is appointed to take place in the Council Room, at 8 p.m., on 18

(*f*) A copy of this list shall be posted at least Seven Days previous to the Annual Meeting to every Member and Associate, who may erase any name or names from the list and substitute the name or names of any other person or persons eligible for such respective offices, but the number of persons on the list after such erasure or substitution must not exceed the number to be elected to the respective offices.

Secretary.

(FORM J. (BYE-LAW 44.)

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

FORM OF PROXY

FOR VOTES ON ALTERATIONS TO CONSTITUTION OR BYE-LAWS.

I,.....being [an Honorary Member, Member, or Associate] of the above Institution, do hereby appoint Mr..... who is [an Honorary Member, Member, or Associate] of the same Institution, to act as my Proxy, and record my Vote at the General Meeting of the Institution, to be held on the.....day of ....., 18....., and at any adjournment thereof.

Signature.....

Address.....

.....

.....*Secretary.*

NORTH-EAST COAST INSTITUTION

OF

ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886-87.

PROCEEDINGS.

ANNUAL GENERAL MEETING HELD IN THE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON WEDNESDAY EVENING, OCTOBER 13TH, 1886.

W. THEO. DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding General Meeting (closing meeting of last session), held on May 12th, 1886, which were approved by the members present, and signed by the President.

The ballot for applications for membership having been taken, the President appointed Messrs. H. Charlton and W. Menzies to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Anthony, James, 6, Northumberland Square, North Shields.
Boolds, James H., Shipyard, Pallion, near Sunderland.
Darley, Henry, 98, Park Road, Newcastle.
Fairman, A. E., 23, St. Bede's Terrace, Sunderland.

Flohr, Justus, 32, Birkenallée, Stettin, Germany.
Garrett, Gilbert H., Messrs. R. Stephenson & Co., South Street, Newcastle.
Harman, Bruce, 10, Hamilton Terrace W., Partick, Glasgow.
Hamilton, James, Jarrow.
Hök, Wilhelm, Deptford Shipyard, Sunderland.
Inglis, John, junior, Pointhouse Shipyard, Partick, Glasgow.
Lindfors, H., Atlas Warf, Gefle, Sweden.
Matthews, James, Messrs. Hawthorn, Leslie, & Co., Forth Banks, Newcastle.
Muir, Robert, 17, Westmorland Road, Newcastle.
Phillips, Walter, 3, West Grove Terrace, Greenwich, London.
Reynolds, William G., 17, Ashfield Terrace East, Newcastle.
Rutherford, George, Wallsend Slipway Engine Works, Cardiff.
Ryder, C. L., 58, Fern Avenue, Newcastle.
Sawyers, John, Messrs. Thomas Wilson & Sons, Hull.
Sharer, Edmund, Shipyard, Pallion, near Sunderland.
Spencer, Ralph, Newburn Steel Works, near Newcastle.
Sutton, Joseph, Elswick Steel Works, Newcastle.
West, Henry H., 14, Castle Street, Liverpool
Westgarth, Tom, Messrs. Westgarth, English, & Co., Middlesbrough.

GRADUATES DESIRING TO BECOME MEMBERS.

Brown, T. R., 14, Dock Street East, Sunderland.
Dickinson, Frederick T., Park House, Sunderland.
Newton, William A., Broughton Road, South Shields.
Shiells, James, 7, Tunstall Vale, Sunderland.
Stevenson, Robert, 6, Mowbray Road, Sunderland.

ASSOCIATES.

Brunton, John, 3, Prior's Terrace, Tynemouth.
Coull, John, 43, Stanley Street West, North Shields.
Foster, Herbert-le-Neve, Steel Works, Messrs. Palmer's Iron and Shipbuilding Co., Jarrow.

GRADUATES.

Armstrong, William S., 63, Croft Terrace, Jarrow.
Blackmore, H., 21, Picton Place, Newcastle.
Burton, Christopher D., 34, Edith Street, Jarrow.
Cooper, Charles R., Engineering Department, Messrs. Palmer's Iron and Shipbuilding Co., Jarrow.
Roberts, T. C., 8, Wilberforce Street, Wallsend.
Wheeler, O., 4, Wilberforce Street, Wallsend.
Wood, Henry A., Longlands, Middlesbrough.

The SECRETARY read the Council's Report and the Treasurer's Financial Statement for last session, as follows:—

COUNCIL REPORT.

THE Council regrets that the finances of the Institution are not in so prosperous a condition as when the first annual report was presented to the members.

The second session has been an active one. Eight papers have been read and discussed, each of which has been illustrated by very expensive plates; hence the cost of printing the Transactions has very much exceeded that of the former session, and this in a great measure accounts for the reduced balance for the year. This matter is now having the serious attention of the Council.

The papers read contain a large amount of practical and theoretical information upon subjects which are at present engaging the attention of engineers and shipbuilders. They are as follows :—

1.—"On the Manufacture of Large Forgings for Marine Purposes." By Mr. H. Cameron.

2.—"On some Considerations regarding the Freeboard of Merchant Ships." By Messrs. I. Mavor and T. Millar.

3.—"On the Application of Hydraulic Pressure to the Driving of Machines." By Mr. R. H. Tweddell.

4.—"On the Construction and Fittings of Salvage Steamers." By Mr. O. Ullstrom.

5.—"On the Stiffening of Collision Bulkheads." By Mr. M. C. James.

6.—"On Forced Draught." By Messrs. J. Patterson and M. Sandison.

7.—"On some Points of Interest in the Designing of Racing Yachts." By Messrs. A. E. Long and W. E. Paton.

8.—"On High Speed Engines." By Messrs. F. C. Marshall and R. L. Weighton.

The Council is pleased to report that the negotiations which were pending at the close of the first session with respect to the setting out of the new measured mile at Hartley have now been completed, and the course has been surveyed and certified by Capt. Tizard of H.M. surveying ship "Triton." The whole cost of the above work has been defrayed by the proprietors of the leading shipbuilding and marine engineering establishments of the Rivers Tyne and Wear; but your Council has thought fit to pledge the Institution to pay the annual cost of maintenance, including the nominal acknowledgment or rental to Lord Hastings and his tenantry, the total cost not to exceed £5 per annum. Large and small charts of the new measured mile can now be obtained from the printer, Mr. Andrew Reid, Newcastle-upon-Tyne. A copy of the small chart forms the frontispiece to Vol. II. of the Transactions of the Institution.

Two very important sub-committees have been elected during the year:—One, "To compile Statistics and Report upon the Progress in Shipbuilding, both in Great Britain and Foreign Countries, during the last twenty-five years." Mr. J. Wigham Richardson is the Chairman of this Committee. The other has been formed, "To investigate and endeavour to formulate a simple but comprehensive rule or measure of the Power of Marine Engines and Boilers, which being (in a measure) scientifically sound and commercially convenient, shall be applicable to the various types and proportions which may obtain in practice." Mr. W. J. Clark was originally appointed Chairman of this Committee, but owing to ill health he was compelled to resign, and Mr. W. Boyd has been appointed in his stead. These sub-committees are still at work.

A sub-committee was also appointed to search for suitable rooms in a central position of the city of Newcastle, to be used as reading rooms for this Institution; but after due consideration the matter was left in abeyance.

The Council has great pleasure in stating that the right of appointing a Governor to the Durham College of Science, in accordance with No. 18 of their Articles of Association, has been conferred upon the Institution; and that the Council by resolution passed on February 3rd, 1886, nominated the President of the Institution for the time being to represent them on the Council of the College.

At the close of the session sundry alterations were made in the Bye-Laws, which it is hoped will prove beneficial to the Institution.

During the session 92 Members, 8 Associates, and 28 Graduates have been added to the list of members. At the close of the session the total number enrolled was 565, viz.:—458 Members, 42 Associates, and 65 Graduates. There have been sundry resignations, and the following have been removed by death, viz.:—W. E. V. Paton, London; A. W. Potts, Sunderland; R. Wyllie, Hartlepool; and M. C. Young, Newcastle-upon-Tyne.

The Council deeply regrets the loss sustained by the death of the late Mr. W. E. V. Paton by misadventure, who, though quite a young man, had already distinguished himself before this Institution; the paper read by him "On the Designing of Racing Yachts," having already gained a high reputation, and copies of it are in great request.

The Council also regrets that another very active member, Mr. W. J. Clark, of Sunderland, has on account of sickness been obliged to resign his seat in the Council.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

STATEMENT OF RECEIPTS AND PAYMENTS FOR SESSION ENDING 31ST MAY, 1886.

Receipts.

To Balance from last Account—					
At Bankers			141	19	2
In hand			8	19	5
				150	18	7
„ Subscriptions for Session 1885–6—					
120 Members at £2 2s. ...	£252	0	0		
37 Associates „ £1 1s. ...	38	17	0		
308 Members „ 10s. 6d. ...	161	14	0		
63 Graduates „ 5s. 0d. ...	15	15	0		
			468	6	0
528					
For Session 1884–5 (paid by new members)—					
1 Member at £2 2s. ...	£2	2	0		
2 Associates „ £1 1s. ...	2	2	0		
1 Member „ 10s. 6d. ...	0	10	6		
			4	14	6
4					
				473	0	6
„ Transactions Sold—					
Per Secretary	£13	3	3		
„ H. Cameron	4	3	6		
„ R. H. Tweddell	22	17	6		
„ O. Ullstrom	1	8	0		
„ A. E. Long	1	7	0		
			42	19	3
				515	19	9
				£666	18	4

Payments.

By Andrew Reid, on account of Transactions and General Stationery			407	9	5
„ Other Printing and Stationery			2	8	6
„ Reporting			17	10	4
„ Advertising			13	14	8
„ Rents			9	6	0
„ Secretary's Salary			75	0	0
„ Secretary's Expenses and Postages ...			63	11	5
„ Treasurer's „ „ ...			5	8	0
„ Auditor's Fee			1	11	6
„ Proportion of Loss, United Conversazione			4	16	9
„ Testimonial to Mr. W. G. Spence ...			15	3	0
„ Sundries			8	10	6
				624	10	1
„ Office Furniture				4	2	2
„ Balance—At Bankers			30	0	4
„ In hand			8	5	9
				38	6	1
				£666	18	4

The Revenue Account for Session ending 31st May, 1886.

	£ s. d.	£ s. d.		£ s. d.	£ s. d.
To Expenditure as per Cash Account ...	624 10 1		By Balance from last Session		150 18 7
Add—Andrew Reid, Balance unpaid	80 9 0		„ Subscriptions per Cash Account ...	473 0 6	
		704 19 1	„ Do. Arrears	40 15 0	
„ Balance, being Surplus at end of Session		133 6 9	„ Transactions Sold, per Cash Account £ 42 19 3		
			„ Do. do. Unpaid... 20 0 6		
			„ Do. in Stock ... 110 12 0		
				173 11 9	
					687 7 3
		£838 5 10			£838 5 10

The Balance Sheet.—31st May, 1886.

LIABILITIES.

	£ s. d.	£ s. d.
Andrew Reid—		
Printing Copies of Transactions ...	152 13 7	
Lithographing	251 15 9	
Folding up	22 16 2	
Covers for Parts	8 7 1	
Binding	4 18 2	
General Stationery, Printing Circulars, &c.	47 7 8	
	487 18 5	
Less—Cash on Account ...	407 9 5	
		80 9 0
Surplus as per Revenue Account		133 6 9
		£213 15 9

ASSETS.

	£ s. d.	£ s. d.
Sundry Debtors—		
For copies of Transactions sold ...		20 0 6
Subscriptions in arrear		40 15 0
Books, consisting of:		
200 copies Transactions, Vol. 1 ...	35 0 0	
144 „ „ Vol. 2 ...	75 12 0	
		110 12 0
Office Furniture		4 2 2
Cash at Bank	30 0 4	
„ Hand	8 5 9	
		38 6 1
		£213 15 9

Newcastle-upon-Tyne, 12th October, 1886.

Audited and Certified,
R. W. SISSON, Public Accountant.

The PRESIDENT said, before moving the adoption of the Report, he should like to make a few remarks upon the same. The Council regretted that the finances were not so prosperous as they could wish. The members might think that the position was not bad, seeing that they had a surplus of £133; but, if they looked into the details, they would find it to be anything but satisfactory to the Council. The actual excess of the expenditure over the receipts for the year was something like £266; but from that there was the stock in hand to deduct, viz., £110, so that the deficiency would thus be £156, which was caused by the excess of cost of the second volume over the first one, the difference being about £300. This difference was enormous, but he thought that most of them would agree that the second volume was well worth the extra cost. The great excess was n the lithographing of the plates, and he for one would not like to see any attempt to reduce the cost by reducing the quality of the work. If the expenditure was to continue on the same scale, he was afraid they would have to look for an increase of revenue in some form or another. The best way, he thought, would be to increase the subscriptions of the 10s. 6d. members, for there were 308 of them, and they only paid 10s. 6d. for what was actually costing the Association £1 1s. It was not, however, the intention of the Council to propose any increase until the end of the current session, and then only if it were found absolutely necessary to do so. The graduates only paid 5s., although the expenses were the same. He, however, thought it was the feeling of the Council that they should not increase that subscription, as they wished to encourage the young members to remain with them. The next point was the question of suitable rooms for "reading rooms," and the only reason for letting that stand over was the financial one. The Council felt they could not, under the existing circumstances, spend more money; but if the subscriptions of the 10s. 6d. members were increased to £1 1s., they could then incur that extra expense. In connection with the Durham College of Science, as their representative he attended the opening meeting the other day, and he was rather sorry to find that their financial state was something like their own. They were spending more than they were receiving; and it struck him that, as they intended to have a chair for Marine Engineering and Naval Architecture, they had a right to look to the leading firms in the district for some assistance, and he thought there were at least forty firms who were well able, and would be willing, to pay something like £25 per annum, and that would put the College of Science in a strong financial position. He did not know that he was

right in throwing out that suggestion; but he thought that, if the College of Science or its principals took the matter up properly, they would have no difficulty in raising funds in that way. He now formally moved the adoption of the report.

This was seconded by Mr. W. MENZIES, and carried unanimously.

The PRESIDENT, W. Theo. Doxford, Esq., then delivered the following Inaugural Address:—

PRESIDENT'S INAUGURAL ADDRESS.

In deciding upon the subject of my address to you this evening, I have kept before me the fact that this Institution is composed of shipowners as well as of shipbuilders and engineers, and that your President's address should therefore be one of general interest. And, as in most of the Presidential addresses to the various associations during the past two years, the present depression in trade and its causes have been dwelt upon pretty fully, I propose to deal more particularly with the remedy for this depression, as far as it affects the members of this Institution. To do this effectually, I propose calling your attention to some points connected with the development of the mercantile marine in recent years, and its present condition, with the view of seeing, if possible, whence improvement in the trades with which this Institution is so closely connected, is to come. What then are the prospects of improvement? And whence is it to come? If we look around us we see a growing feeling that the worst point has been touched; we see freights improving, though slowly; we see confidence gaining ground amongst commercial men—a confidence which will continue to strengthen the more we are assured that we have got a stable government, and that there is not to be war abroad—at any rate for some time to come. Now, don't misunderstand me. I do not mean to say that war would not improve our trade—quite the contrary; for hitherto war has always been an enormous gain to the shipowner, and, therefore, to the shipbuilder, whilst it lasted; but this great temporary prosperity has always been followed by a corresponding depression.

For some time past we have been in the worst conceivable position, for neither have we been at war, nor have we been able to depend upon a lasting peace, and nothing kills trade sooner than uncertainty, or a want of confidence. But although there are many signs of coming improvement in the general trade of the country, I fear that it will be a long time yet ere shipbuilders and engineers feel the benefit of it to any considerable extent by orders coming in for new steamers. There will be such orders, and they will gradually increase; but after the serious losses which many shipowners have sustained, it must take a considerable time, and require an accumulation of profits, before they again feel justified in investing largely in new vessels. But, gentlemen, if we cannot look for

immediate improvement in the shipbuilding and engineering trades in this direction, there is another direction from which not only immediate but also sustained improvement must come if shipowners are to put their present vessels into a fit state to compete with others now being built, and that direction is the work to be done to realize that object.

In the first place, I will deal with the present condition of the steam fleet of the world, and to enable me to do so satisfactorily, I have prepared the following Table—taking Lloyd's "New Universal Register" as a basis—which shows at a glance, in periods of five years each, the number and sizes of steamers, above 200 tons gross register, built since 1855, which were afloat when the Register was issued, and which I venture to think contains information new, important, and also interesting to every member of this Institution :—

NUMBER AND SIZES OF STEAMERS ABOVE 200 TONS GROSS REGISTER BUILT SINCE 1855 AND NOW AFLOAT.

1856-60.		1861-65.	1866-70.	1871-75.	1876-80.	1881-86.	Totals.
Tons. No. Tonnage.							
200 to 500	146 — 48,699	193— 67,549	189— 60,850	370 — 123,112	327 — 107,415	612 — 202,295	1,837— 609,920
500 to 1,000	76 — 57,524	267—192,219	268—199,544	416 — 305,546	352 — 261,405	557 — 409,411	1,936-1,425,649
1,000 to 1,500	21 — 25,216	82—100,572	157—191,112	363 — 437,899	354 — 438,024	520 — 649,178	1,497-1,842,001
1,500 to 2,000	13 — 22,170	50— 87,261	73—126,516	178 — 305,263	319 — 557,684	553 — 954,553	1.186-2,053,447
2,000 to 2,500	8 — 18,317	26— 56,997	39— 86,413	96 — 212,103	130 — 216,170	339 — 686,351	638-1,276,351
2,500 to 3,000	6 — 15,835	16— 44,898	25— 68,939	63 — 171,268	38 — 105,680	180 — 443,538	328— 850,158
3,000 to 4,000	4 — 13,631	10— 33,117	29— 94,236	76 — 258,962	52 — 177,286	147 — 508,457	318-1,085,689
4,000 to 5,000	....	11— 49,371	6— 25,573	20 — 88,796	6 — 25,708	71 — 308,843	114— 498,291
5,000 and up.	1 — 18,915	....	....	4 — 20,583	3 — 16,045	27 — 158,511	35— 214,054
	275—220,307	655—631,984	786—853,183	1,586-1,923,532	1,581-1,905,417	3,006-4,321,137	7,889-9,855,560
Average	801	965	1,085	1,212	1,205	1,437	1,249

Before dealing with the figures contained in this Table, allow me to explain why the totals do not agree with Table No. 1 in the Register. Table No. 1 gives the total number of steamers above 100 tons of whatever age, but I have thought it advisable to leave out all steamers below 200 tons, as probably not affecting the points at issue, and also all those built before 1856 as being practically obsolete. The numbers in the Register, viz.:—9,642 steamers of 10,291,241 tons gross are thus reduced to 7,889 steamers of 9,855,560 tons gross, and it is with these latter I now propose to deal.

One important fact which I wish to bring to your notice, is the great

increase in the size of steamers. Comparing the first and the last of the six periods with which I am dealing, I find that the tonnage of steamers of—

200 to	500	tons	has increased	...	four-fold
500 „	1,000	„	„	...	seven „
1,000 „	1,500	„	„	...	twenty-five „
1,500 „	2,000	„	„	...	forty-three „
2,000 „	2,500	„	„	...	thirty-seven „
2,500 „	3,000	„	„		twenty-eight „
3,000 „	4,000	„	„	...	thirty-seven „

Showing the largest increase in steamers of from 1,500 to 2,000 tons. Taking, however, the two latter periods in the Table it will be found that the larger developments are now taking place in vessels of 3,000 tons and upwards.

You will see from the Table that the average increase in size has been very steady, although rapid, with the exception of the years 1876-80, when it practically remained stationary, the advance having been from 735 tons in 1856-60 (leaving out the "Great Eastern") to 1,437 tons in 1881-86.

This is a wonderful development to have taken place in so short a space of time as thirty years, especially when we consider that the art of shipbuilding is not of recent origin. Who can say how many thousands of years elapsed between the setting afloat of the first small vessel, and the date when the average size had increased to 735 tons? And yet in but thirty years we have doubled that average.

The next important, I may almost say startling fact, which is brought to light by this Table is that nearly one-half of the tonnage now afloat has been built since 1880—that is within the past five-and-a-half years. The ages of the various vessels are as follows, viz :—

Built 1856 to 1860 inclusive		275	steamers	220,307	tons gross.
„ 1861 to 1865	„	655	„	631,984	„ „
„ 1866 to 1870	„	786	„	853,183	„ „
„ 1871 to 1875	„	1,586	„	1,923,532	„ „
„ 1876 to 1880	„	1,581	„	1,905,417	„ „
„ 1881 to 1886 (only part 1886 included)		3,006	„	4,321,137	„ „
		7,889		9,855,560	

From these figures you will see that 44 per cent. of the total tonnage has been built since 1880; and that since 1870 the enormous number of 6,173 steamers with a total tonnage of 8,150,086 as against only 1,716 steamers of 1,705,474 tons for the previous fifteen years.

Now so much for the size of our fleet; but what of its condition?

It is well known that many vessels now afloat are obsolete, and can never be made to pay again as cargo or passenger-carrying vessels, owing to the improvements which have taken place, not only in the machinery—which might be altered—but also in the proportionate dimensions of the hull, and the better adaptation of the general arrangements, and the model, to the special trade for which the vessel is intended.

Then there are other vessels which it is almost impossible to navigate profitably now, but which may be turned into very desirable property by taking out the present engines and boilers, and putting in triple expansion engines, with high pressure boilers.

Let us then divide the present fleet into three classes, and thus arrive as nearly as possible to a knowledge of its present condition, so that the shipowner may realize his position, and what he has to face to put his fleet in order, and the shipbuilder and engineer may know the work that lies before them.

In the first class, I propose to include all boats of modern type, and which may be thought fairly capable of earning profits for some time to come, although not fitted with triple expansion engines.

In the second class, I include those boats which must be re-engined, or have their engines altered to triple expansion, to give them any chance of competing favourably with the more modern type of boat.

In the third class, I include those boats which I consider obsolete, and not worth the cost of altering.

	Boats.	Tons.
For the first class, I take all boats built since 1880, although there are comparatively few of them with triple expansion engines, say ...	3,006	.. 4,321,137
Then of those boats built from 1876 to 1880, I take one-half as being fairly economical, and not needing to be altered at present, say ...	791	... 952,709
Total	3,797	... 5,273,846
For the second class, I take the balance of the boats built from 1876 to 1880, say	790	... 952,708
All boats built from 1871 to 1875	1,586	... 1,923,532
And 25 per cent. of those built 1866 to 1870, say	197	... 213,296
Total	2,573	.. 3,089,536

	Boats.	Tons.
For the third class, I take the balance of those built 1866 to 1870 = 75 per cent., say ...	589	639,887
And all before 1866	930	852,291
Total	1,519	1,492,178

In considering these figures, gentlemen, you must remember that they are only approximate—in the nature of things, they cannot be otherwise—for taking any one particular boat, it may be a moot point as to whether she is obsolete, or worth re-engining—whether she is good for more work, or should be altered at once. But I think I have rather under than over-estimated the tonnage in the second class, and it is with this class that I wish now more particularly to deal. Well then, can we arrive approximately at the amount of work to be done to those 2,573 boats, and the cost of doing it? Let us assume that only one-half need to have new engines and high pressure boilers; that would give, say—

1,286 boats, with gross tonnage 1,544,768, which I estimate would cost for engines and boilers	£5,000,000
Shipwork, probably	1,000,000
Cost of altering the engines of the other 1,287 boats, including new boilers, say	3,000,000
Shipwork, say	500,000
	£9,500,000

Now, if I am correct in my premises and deductions, this amount of £9,500,000 should be spent at once on these 2,573 boats, or they will have no chance of competing favourably with other boats now building. But the shipowner naturally asks, Will it pay? I will endeavour to put him in a position to answer the question for himself.

I estimate the engine power of these 2,573 boats to be 1,730,000 indicated horse-power, and taking the consumption at 2½ lbs. per horse-power per hour (and considering the boats I am dealing with, I feel pretty sure that I am within the mark), and allowing 250 steaming days in the year, we have a total consumption of 11,585,000 tons of coal; but let us reduce this to 10,000,000 tons, for steamers do not always run at their full power, and then, if we take a saving of only 20 per cent. for the triple expansion engines, we have a saving of 2,000,000 tons of coal per annum. Is it too much to put this as worth 20s. per ton, considering the extra cargo which will be carried, and the first cost of the coal? I think not,

for although in the North Atlantic trade the saving may only be about 15s. on the round—owing to the want of cargo outwards—yet, in other trades the saving will be much greater, so that 20s. may be taken as a fair average.

Now, to estimate the true advantage to be gained by adopting triple expansion engines and high pressure boilers, we must deduct from the estimated cost of £9,500,000 the amount which must necessarily be spent on new boilers and shipwork, whether the engines are altered or not, and this we cannot put at less than £3,500,000, for it is notorious that many steamers can hardly go to sea again without new boilers and a general overhaul, and that the great bulk of the steamers I am now dealing with must have very considerable sums spent upon them within a very short time. This estimate leaves a balance of £6,000,000 as the cost of adopting triple expansion engines, against which we having a saving in fuel of £2,000,000; also a saving in wages, as there would be 2,000,000 fewer tons of coal to handle, besides other expenses. Surely, a good return for the sum expended.

To illustrate this, take a boat with engines indicating, say, 1,200 horse-power, but whose boilers are worn out. To replace these boilers with new ones will cost, say, £2,000, and when done you have gained nothing in economy. But take out the engines and boilers altogether, and put in triple expansion engines and boilers of, say, 160 lbs. pressure, which can be done for about £7,000 (excluding shipwork in both cases), and take the consumption of the old engines at 2½ lbs. per horse-power with 250 steaming days in the year, which gives a total consumption of 8,000 tons, we have a saving—taking it at 20 per cent.—of 1,600 tons per annum, or £1,600 against the extra cost of £5,000, or 30 per cent.

From what I have said you will see that there is an enormous amount of work to be done, especially by engineers, in addition to the ordinary new work; but this is not all, for within the next ten years something like 2,500 of the steamers which I have placed in the first class should also be re-engined, or altered, and these, taken on a similar basis to those in the second class, would cost another £10,500,000.

From these calculations, it would appear that there should be some £20,000,000 spent during the next ten years, or an average of £2,000,000 per annum, in re-engining the present fleet of steamers, and doing other work necessary to enable them to compete favourably with the class of steamers now being built. Will this sum be spent? I fear not. But in proportion to the amount not spent, a number of steamers will become

less and less capable of competing and become of less and less value, until the owner finds that his property has slipped away from him—property which might have been saved, had the necessary expense been incurred in good time.

Now, if the owner has to find this extra capital, it is the duty of the engineer and the shipbuilder to see that the amount is laid out in the best possible way; and this brings me to an important point: have we, as engineers, now produced, in the triple expansion engine, the best type of engine for the work to be performed? We are only at the commencement of the transition, from the compound engine with boilers working at 70 to 80 lbs., to the triple expansion engine with boilers working at 150 to 160 lbs., and already there are signs of a further step forward, to quadruple expansion, or rather expansion in four cylinders; but, until we are in a position to adopt much higher pressures than even 160 lbs., there will be no economy in fuel gained by the four over three cylinders, and as we cannot go very much beyond that pressure with the present type of boiler, shipowners have nothing to fear on that score at present; and yet it may be advantageous, in many cases, to use four cylinders when altering the ordinary compound two crank engines to work at the higher pressure.

It is for you, gentlemen, to consider well these questions, and to work out the problem of still greater efficiency in the propelling power of our steamers; and one of the great advantages of such an Institution as this is that it enables the writer of a paper to have his ideas thoroughly criticised by practical men before he puts them into practice, and he is thus enabled to avoid the pit-falls into which he might otherwise stumble.

Now, I have dealt with the present steam fleet and its condition, and have shown you, approximately, the amount of work to be done to put it in good working order. The figures I have given you are of serious importance to the shipowner on account of the large additional capital required, and to the engineer and shipbuilder, because the expenditure of that amount of capital would enable them once more to keep their works going something like full time.

But there are other reflections caused by the consideration of the Table which I have laid before you, for we have seen that there has been a gradual and rapid increase in the average size of steamers during the last thirty years, and this raises the question, Is the size to go on increasing? I think so; for it was the introduction of iron in place of

wood which first enabled us to materially increase the size of vessels; and now with the introduction of steel there is hardly any limit to which we may not go, as far as mere strength is concerned. Owners have also found out that the larger the vessel is the better she will pay, providing that there is the cargo and the necessary accommodation for her; and we further see that a constant development is taking place in most of the large harbours of the world—a development more than keeping pace with the increasing size of the vessels using them.

Now, it is our duty as shipbuilders and engineers to assist this development by studying carefully the problems involved in the designing and construction of these enormous vessels and their engines and boilers, ever bearing in mind the great desideratum that the cargo shall be taken in at one port, carried safely to, and discharged at the other, at the lowest possible price per ton.

In passenger steamers the problems become more complicated, for in addition to the other requirements, we have that of enormous speed, for people are not now satisfied to travel across the waters at the speed which was considered satisfactory only a very few years ago. Now, although our Institution is only in its third year, I think we have several members both willing and able to solve these problems satisfactorily, and who are quite prepared to build steamers which will excel any now afloat, if it is the desire of the shipowner to have them built; the only point I would like to urge, so as to prevent failure, is that each step forward should be gradual and well considered, due advantage being taken of previous experience.

Let us be satisfied if we beat previous record by one or two knots at a time, and not aim at jumping up from 16 or 18 knots to 30 or 40 knots, as we heard was being attempted on the other side of the Atlantic a short time ago.

We will reach 30 knots some day, but it will only be done step by step.

These are high speeds to contemplate, but probably engineers may be assisted in obtaining them, not only by the diminished consumption caused by the adoption of triple expansion engines, but also by the decreased weight of machinery caused by the use of forced draught and higher piston speed.

Now, many of us have felt our spirits cast down during the past two or three years when looking at our almost empty workshops, and the thousands of workmen standing idle in the streets, and the gloom over many has grown deeper and deeper until some have almost despaired of the future.

But I hope that I have done a little to dispel this gloom, both from employers and employed, for I have shown you whence work must come if our shipowners are to maintain their proud position.

And let us also bear in mind that truly fundamental law—the law of change—a law which allows nothing to stand absolutely still, for if we do not move forward we recede, and our places are filled by others. Every improvement in marine engineering, every development in the size and power of our steamers, enforces this one great law, and the shipowner who will not resolutely face the inevitable must stand to one side, and see a new generation take his place having the nerve and determination to keep well to the front.

Look where we may we see this inevitable law holding sway, and it means work for the worker. We have seen our "wooden walls" displaced by those of iron; we are now seeing the rapid substitution of steam as a driving power in place of sails; we have seen the substitution of the screw for the paddle; of the surface condenser for the jet condenser; then the step forward to the compound engines working at 80 lbs.; and again to the triple expansion engines of 160 lbs.

In material, we see iron, which so lately superseded wood, now giving place to steel; and so forward we must continue to move, ever advancing to something better if we are not to be left behind in the race.

May we then, as members of this Institution—as shipbuilders—as engineers—as shipowners—each and all be determined to be the first and not the last in this race; and then we need never despair of the future, for we shall continue to build the fleets of the world, and help to maintain our country as Empress of the seas.

Mr. Wm. Boyd said, it had occurred to him, that owing to preceding events it might be suitable that he should take upon himself to propose a vote of thanks to the President for his very admirable address. He (Mr. Boyd) better perhaps, than most people in the room, could appreciate the labour involved in such an address as that just read; and he could also, on behalf of the audience, convey their appreciation to the President for the figures and statistics which he had given. These statistical papers, of which this was one to a certain extent, were sometimes dry reading, and were sometimes apt to convey an impression of being a lot of figures strung together; but the present address was something more than this. The position of their President in the profession and his

high character would enable them to feel sure that the figures presented to them that night were absolutely reliable, and, that being so, the deductions and conclusions to be drawn therefrom afforded a most wide and interesting study. The address was, he thought, a good example of the great advantage to be derived by such an Institution as ours, by the law of change and progress referred to in it. It was essentially different from the two previous addresses, and, in fact, was typical of the advance from the "compound" engine of 80 lbs. pressure to the present "triple expansion" system. With regard to the subject treated upon in the address, he would take the liberty of saying a word or two, because he knew, going back to his own experience, it would be satisfactory to their President that the address should not be looked upon simply as a scientific treatise, but that it should, so far as their limit of time went, be treated upon its merits. It opened up a number of interesting questions, with which many gentlemen present that night were capable of dealing. There was, of course, an immense deal of matter in the President's address, which could be dealt with at very great length, but there were only one or two points upon which he wished to claim their attention. In one of the local papers, which were good enough to make a very favourable notice of their Institution during the last few days, he thought that one very good point was brought out, and it was this :— "That because a paper had been read upon any one given subject, it would be unwise that that subject should be considered entirely exhausted." Their President brought out this point to a certain extent, but he ventured to think not to the extent to which it might have been. The President, on page 16, alludes to the weight of machinery, but only incidentally. Now, from such cases as he (Mr. Boyd) had had the opportunity of investigating alterations to vessels, in almost all of them the extra cargo to be carried, due partly to the saving of bunker capacity, was considerable, and his point was that, although Mr. Marshall and Mr. Weighton had in their paper dealt very exhaustively with the comparative weights of the "high speed engines," still he believed the subject was not an exhausted one, their paper had only touched the fringe of the matter. In the subjects of weights of machinery for cargo-carrying vessels there was a field for investigation which was well worth the attention of the members of that Institution. There was, he continued, an old proverb which said : "Hope springs eternal in the human breast," and they had to draw largely upon their reserves in this respect, and he thought their President had given them a great lift forward that night ; but, apart from the sentimental assistance, he believed their President had brought subjects before them which would be well worth the considera-

tion of all those who were engaged in such enterprises, and he thought that their Institution owed a very cordial vote of thanks to their President, which he had much pleasure in proposing.

Mr. R. S. WHITE said, in rising in response to an invitation to second the vote of thanks to their President for the very admirable address he had delivered to them, he did so with considerable diffidence; at the same time he had great pleasure in bearing testimony to the great importance of the address, from a shipbuilder's point of view, in the information it had brought before them; and no one could look at the Table on page 10, wherein the immense production since 1880 was given, without a feeling of surprise at the fact, that nearly one-half of the whole steamship tonnage afloat had been produced since that date; and he thought that during those four or five years very few engaged in shipbuilding realised the tremendous amount of work that was being turned out, although it was evident to each and all of them, very much pressure had been brought to bear on the power of production during that time: their thanks were due therefore to their President for the great care and trouble he had taken in bringing so much valuable information before them. They might not be able to look forward to repeat in the next year, or even perhaps two years, their experience of 1880 to 1884, during which the great bulk of the four and a half million tons referred to by the President had been produced. He hoped, however, that the shipowners, whose interests were so much concerned and at stake, would favourably consider the proposals and anticipations made to them by the President, and that they would be induced to at once dispense some large proportion of the proposed twenty millions. He considered, however, at the same time, that the proposals made came rather hard on shipbuilders as they were thrown somewhat in the cold, the bulk of the proposed expenditure being allocated to engineers and ship repairers, rather than the shipbuilder. It, therefore, becomes the duty of the latter, to see whether it is not possible so to design and build new vessels of increased tonnage, of steel instead of iron, and with triple expansion engines and other "latest improvements," that they would give such advantages in the cheap transit of goods from one port to another, as would beat altogether any proposals that could possibly be made for converting or re-organising old steamers. He thought this could be done, and, if so, then the shipbuilder might also look forward to a very fair share of the proposed expenditure. He concluded by seconding the vote of thanks.

Mr. JOHN PRICE said, he rose for the purpose of giving a very cordial welcome to the President, and, having the most intimate possible relations with Sunderland, had all the more satisfaction in seeing a

Sunderland man occupying so ably the distinguished position of President of this Institution. He begged to call to the attention of the meeting that the discussion, so far, had proceeded in the hearing of members who are shipowners. The observations of members taking part in the discussion should, therefore, not be open to destructive criticism from their shipowning friends, and, therefore, he would venture to point out one or two instances in which the admirable address of their President might be open to objection. (1) The inference likely to be deduced from the proportion which the tonnage built in the last five years bore to the whole of that now afloat, namely, 44 per cent., would be that an excess of tonnage had been built within the first named period—1880-86—in comparison with what had been built in the other periods mentioned in the address. If, however, we consider that the law of change has been operating upon vessels built in the earlier periods, and has not had a proportionate time to operate upon the tonnage built within the last five years, it will be seen at once that the comparison of one period with the other is scarcely fair. To have shown the amount of tonnage recently built with the amount built in earlier periods, would have enabled a correct estimate to have been formed of the total produce in the various periods; but to say that we have a certain proportion of the whole built within the most recent period, and but only a very much smaller proportion afloat of that built in the much earlier period, is to ignore the effect of the law of change, or, in other words, of the operation of disasters and other causes which remove tonnage out of existence, and to lead to the unsound inference that building of late years has been greatly in excess of the requirements of trade. To give this an application he would take the case of his own company, who, during the last thirty years, have built about 530 sea-going vessels. Of this number, about 350 are now afloat. During the last five years 140 of these have been built, leaving 210 as having been built before 1880. If it should be argued, therefore, that our building during the past five years has been in the proportion of 140 to 210, namely, 66 per cent. of all those afloat, it would create an entirely erroneous impression. Particularly will this appear when it is further considered that of the 530 vessels, 180 have been removed from existence by the operation of ordinary causes, while only four of which have been removed during the past five years. He thought this conclusively showed that to deduce any argument from the proportion of tonnage built during the last five years, as compared with the total tonnage now afloat—as either against or in favour of our present capabilities of production—would be impracticable. Briefly, he would say that the tonnage built during the last five years was not abnormal, no more than

what usually takes place under ordinary circumstances, when production is stimulated by high prices, and a subsequent depression throws out of employment a portion of what has been produced and employed up to the period when the depression set in. During the last five years it is probable that the longevity of vessels has been promoted by improvements in design and machinery, because everything which is an element of safety—and some elements which are purely those of economy—have a direct effect on lessening the chances against the life of a ship. The enormous tonnage produced during the past five years is not due simply to the normal growth of trade; the large proportion built to foreign account is only to be explained by supposing that foreign sailing wooden vessels have been substituted by steamers. Altogether, new trades have also been developed, and these two circumstances have added their demands for tonnage to the normal development of trade. He believed it scarcely practicable, with the present means of communication, that the intelligent communities of shipowners and shipbuilders in Great Britain should commit so great a folly as to largely overbuild. This was no doubt done in earlier periods, more or less, but is less liable to be done now. (2) With regard to the effect of recent improvements in marine engines upon the tonnage now in existence, alluded to so ably by the President, he wished to express a very clear opinion that the conversion of old ships, in many cases, would run a very tight race with the very best types of new ships fitted with new engines. It is possible, in many cases to-day, to buy old vessels at such a figure as would enable them to be re-engined and boilered at so low a value as to make them a better investment—notwithstanding differences of type and material of which they are built. He would give a case in point, where a vessel, which he knew capable of carrying 2,600 tons, and which, at the present time, was entirely devoid of profit-earning power and not worth more than £5,000—the value of the hull. If £5,000 were spent on this vessel in replacing the engines and boilers by those of the newest type, she would then represent a value of £10,000, and, carrying 2,600 tons, would become a better investment than anything that could be built. In his opinion, many hundreds of vessels, built within the last period named by the President, would not suffer by comparison with those built to-day as to form and general fitness for trade, and which, when the time came, if fitted with new machinery, would be equal to anything that could be produced at the present day, with the single difference that steel ships being lighter, carry relatively a larger dead-weight. He agreed with the President that the matter was of the first importance to shipowners, next in importance to themselves, and that these works should be undertaken,

with the least possible delay, to bring the enormous amount of idle capital into operation. He concluded by bearing testimony to the excellence of the President's address.

Mr. S. P. AUSTIN said, as a shipbuilder from Sunderland, he should not like the opportunity to pass without expressing the extreme pleasure they, on that river felt, at having one of its shipbuilders as President of that Institution. He was somewhat alarmed at the figures the President had given them, for whilst he had pointed out from whence a large share of work might come, in altering existing steamers, if the builders of the United Kingdom had during the past six years produced half of the steam tonnage of our present mercantile fleet, the operation could be readily repeated. It seemed to him, therefore, that our power of production was too great for the world's demands, and he thought they would have to curtail their production. No doubt the wants of the world were increasing steadily, and they, as Englishmen, were resolved that no foreign nation should take away from them what they felt to be their right, and that was the construction of the lion's share of the carrying power of the world. He should like to hear the subject discussed further, as it had now arrived at a most important point. His own impression was that they had the power of producing far more vessels than the world could continue to give them orders for. He thought it would be very much better to have a steady supply of a moderate number of orders rather than a few years of excessive demand, alternately followed by a number of years of famine. He was of opinion that, as shipbuilders and engineers, they would have to resolve generally, for it could not otherwise be introduced, to revert to the system to which they were accustomed in the construction of the wooden walls, he meant the system of building vessels on time wages, to the exclusion of piece work, and so continue to carry out the works with more satisfaction to the employer and employed. The piece work system, in his opinion, was very much at the root of the evil of the depression they were suffering from. If the time work system were universally introduced, he believed, from his own experience, that the change would, after a fair trial, be appreciated by both the employer and employed. He concluded by supporting the resolution.

Mr. G. B. HUNTER, in rising to support the vote of thanks, said, the subject chosen by the President for his address was indeed a very interesting one. It must have been felt to be so by our shipowning friends, and it must also have been interesting to themselves as engineers and shipbuilders. Although it seemed to him that the shipbuilders were rather shared out, still he felt encouraged and very much

so both in hearing the address of the President, and in the thoughts which it had suggested. It had been pointed out by Mr. White that there was a possible alternative mode of spending what must be expended, and that instead of solely converting the engines or putting new engines into old hulls, it might be thought more profitable to spend the money in new vessels altogether. There was one thing to which Mr. Price had omitted to give due weight, and that was, that the new vessels which were now being built were not iron but steel ships. It was a great improvement to have, instead of either a new or old iron ship, a steel ship, and one larger and better proportioned—to have a new tool instead of one half new and half old. He did not contend that the advantages to be gained from the use of steel, instead of iron, were quite so large as the President estimated, from the adoption of the triple expansion engines. Still they did know there was a very substantial improvement, that steel ships were being built to compete very much better than old iron steamers with the low rate of freights now obtainable. In striking a balance of advantages and disadvantages between re-engining and re-building, the advantages would be found more largely on the side of re-building than Mr. Price indicated. Mr. Austin, he thought, took rather too desponding a view, especially as the President in his address had only dealt and only meant to deal with one source, and that not quite the most important source, from which they might expect work to come. Many considerations could be touched upon, to show that they might expect very much more shipbuilding work than the President had indicated. Taking the President's figures showing the amount of tonnage of steamships afloat to be about ten million tons, he thought they might fairly estimate that the annual loss would be at least 3 to 4 per cent., and to replace that annual loss, say, at 3 per cent. only, would give them 300,000 tons a year in addition to what the President stated; multiplying this 300,000 tons by 10 would give them a tonnage of 3,000,000 to supply at something like £12 per ton register over all (which he thought very moderate, taking into consideration the small vessels and large passenger steamers), this would add a further sum of £36,000,000 for the ten years. In addition, the steamers placed by the President in the third class as obsolete and not worth the cost of altering, about 1,500,000 tons, would have to be replaced, and they might also hope for an expansion of the world's commerce such as would require an addition of five per cent., or 500,000 tons annually, to be made to the world's steamship tonnage. The President in his address had not dealt at all with sailing ships; of course, the work of replacing sailing ships by steamships would

go on further. There was the prospect of a great volume of shipbuilding and engineering, but a still greater power of producing it.

Mr. C. W. HUTCHINSON said, that as a Newcastle man, he rose to express his satisfaction at the prominent part which had been taken in the work of the evening by Sunderland members. But he would remind them that the paper which had just been read (if the inaugural address might be called a paper) was only the second that had been contributed from Sunderland. He also desired to support the vote of thanks to the President for his address, and, referring to it, he would remark in passing, that the gain from reduced quantity of coal required when old engines were replaced by those more efficient was not to be calculated simply from the prices of coal in Newcastle, but also on the price of coal in foreign ports, which was often a very large factor of the profits. With reference to the general increase of size of steamers, it was interesting to see how these appeared to have the power of demanding increased port facilities, as, for instance, about twenty-five years ago, the port of Newcastle was available only for vessels up to 500 tons, whereas, at the present time, a vessel of ten or eleven thousand tons is building above bridge, and will soon be floating and moving on the Tyne.

Mr. WM. BOYD then put the vote of thanks to the meeting, which was carried with acclamation.

The PRESIDENT said, in the first place, would they allow him to thank Mr. Boyd, Mr. White, and the other gentlemen for the way in which they had proposed the vote of thanks? Unfortunately, it was a little difficult to reply to the speeches which had been made, because they had been so favourable; he had expected to have had some adverse criticism. He had only merely touched the fringe of the whole question. For instance, Mr. Price had touched upon several points, which he had in mind, but he felt there would be no end to his address if he went fully into all the questions connected with it. He limited himself to one branch of the subject, and that was to ascertain from whence immediate improvement might be expected to come for the engineer and shipbuilder. If he had gone further, he might have touched upon sailing ships, of which he saw by Lloyd's book there were something like 11,000,000 tons afloat, and of which a large proportion must be replaced by steamers, for the loss every year in sailing ships was much greater than the new sailing tonnage built. He would say nothing more than express his thanks for the way in which they had received his address, which more than repaid him for any trouble he had taken.

This concluded the business of the meeting.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886–87.

PROCEEDINGS.

SECOND GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON WEDNESDAY EVENING, 10TH NOVEMBER, 1886.

W. THEO. DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the preceding Annual Meeting, held in Newcastle-upon-Tyne on October 13th, 1886, which were approved by the members present, and signed by the President.

The ballot for new members having been taken, the President appointed Messrs. A. Laing and J. Tweedy to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Allison, John, 2, St. George's Road, Leyton, London, E.
Bell, Robert T., 2, William Street, Jarrow.
Buckland, Henry B., Walker Boiler Works, Low Walker.
Crawford, James, 9, Custom House Court, Quayside, Newcastle.
Davison, John W., The Crescent, Low Fell, Gateshead.
Dixon-Brown, Lionel D., Unthank Hall, Haltwhistle.
Edmiston, James B., Ivy Cottage, Highfield Road, Liverpool.
Gilroy, Thomas R., Messrs. Harland & Wolff, Belfast.
Hamilton, John, 17, Mowbray Street, Heaton.
Headlam, Robert, 5, Edward Street, Stockton-on-Tees.

Milton, J. T., Messrs. R. & W. Hawthorn, Leslie, & Co., St. Peter's-on-Tyne.
Morrison, Robert, 5, Challoner Terrace, South Shields.
Plotnicki, Edmund C., 102, West Percy Street, North Shields.
Readhead, W. B., Sea View, South Shields.
Robson, Thomas, 14, Richmond Crescent, Barnsbury, London, N.
Rowan, James, 231, Elliot Street, Glasgow.
Shotton, John W., 36, Heaton Park Road, Newcastle.
Sievewright, George W., 5, Radcliffe Terrace, Hartlepool.
Snowden, William F., Salter's Road, Gosforth, Newcastle.
Soulsby, James C., 2, Stacey Road, Cardiff.
Tinn, Frederick D., 5, Hawthorn Terrace, South Shields.
Wiles, John W., 123, Clifford Street, Byker, Newcastle.
Wilson, R. D., 84, Gloucester Street, Newcastle.

GRADUATE DESIRING TO BECOME MEMBER.

Garratt, Herbert A., 16, Grove Street, Newcastle.

ASSOCIATES.

Carr, Ralph, 25, Claremont Place, Newcastle.
McNabb, Thomas, Cail's Buildings, Quayside, Newcastle.
Ward, Joseph, Messrs. Wallsend Slipway Co., Wallsend-on-Tyne.

GRADUATES.

Anderson, Robert, 21, Picton Place, Newcastle.
Blackett, Walter, 6, Windsor Crescent, Newcastle.
Bramwell, Balfour, 20, Beverley Terrace, Cullercoats.
Miller, Thomas B., 3, The Crescent, Gateshead.
Munro, Alexander, 20, Linskill Terrace, North Shields.
Munro, Henry J., 47, King Street, North Shields.
Noble, Robert, 13, Prospect Terrace, Jarrow.
Towers, Edward, jun., 4, Latimer Street, Tynemouth.

The following paper, prepared by Messrs. B. G. Nichol and J. Gravell, on "The Use and Transport of Liquid Fuel," was then read:—

THE USE AND TRANSPORT OF LIQUID FUEL.

By Messrs. B. G. NICHOL and J. GRAVELL.

Since the first oil well was drilled in America, in the year 1859, the petroleum industries of the world have advanced apace, and this natural oil, apart from all other purposes to which it is or may be applied, is apparently destined to prove a formidable rival to coal as a fuel, which it has largely superseded in certain countries at the present day.

General Valentine Baker, who traversed the Caspian region in 1873, says of it, in his "Clouds in the East," "The fuel is not highly inflammable, and its use seems perfectly safe and under control. Vessels originally fitted for burning coal can burn this liquid fuel with very little alteration. One stoker is sufficient for a large steamer. All the engineers of vessels burning petroleum speak in the highest terms of the fuel." Were the petroleum-producing areas confined to the Caspian region, the day might probably be far distant when the use of this valuable natural product, as fuel, may become general.

Fortunately for the world, but perhaps unfortunately for coal owners, this is not so. Mr. Herbert Tweddle assures us that petroleum exists along the slopes of all the great volcanic uplifts on the surface of the globe, although at present there are but few localities from which it is raised in large quantities.

From a careful study of the geological formations, he concludes that the petroleum regions of Europe and Asia form one continuous zone, of varying width, passing in a diagonal direction across Europe, and terminating in the plains of Central Asia, embracing nearly all Scotland and England south of the Grampians, Hanover, Bohemia, Galicia, Moldavia, Roumania, Transylvania, with Hungary, the Crimea, both slopes of the Caucasus chain, including Baku, the Transcaspian regions, the Island of Tcheleken, Krasnovodsk, the Neft Gora, the Heri Rud, and Tashkent. The areas in Northern Italy along both slopes of the Apennines, and at Zante, together with those of Bosnia, he regards as offshoots of the main system, and, doubtless, so are the rich, though very little worked areas in the Punjaub and recently annexed Burmah, if indeed they are not a continuation of the same great zone.

The petroleum areas in America appear to occupy a similarly comprehensive zone, extending from Gaspe on the St. Lawrence in the north to the Gulf of Mexico in the south, where it joins the mountain chain of

the Andes and Sierra Nevada, along the western slopes of which petroleum areas are found. The petroleum springs of Cuba, Trinidad, and other West India Islands being but ramifications from the main system, just as the areas of Northern Italy are offshoots from the Indo-European zone.

Extensive petroleum-bearing areas exist in Australia, China, and Japan, and the recent great volcanic upheaval in New Zealand is ample proof that petroleum exists there in large quantities.

Seeing then, that this valuable product of nature exists over such vast areas of the earth's surface, it is but natural to suppose that, in the near future, it will be worked in every country where it may be found in sufficient abundance to justify the investment of capital; but, meanwhile, it cannot be other than profitable to shipowner, shipbuilder, and engineer to minimise the cost of transport and to economise consumption, as far as that can be done.

The supply of liquid fuel may be considerably augmented by distillation of shale, and of the waste on pit heaps, also by recovery of the bye-products in the manufacture of coke.

M. Gulishambaroff, the leading authority in Russia on petroleum, gives an analysis of Pennsylvanian and Russian oils and of petroleum refuse, as shown by the following table, which also contains the average composition of 98 samples of British coal, ascertained by Delabeche and Playfair, with the heating power in thermal units, computed according to the values of the component parts, experimentally established by MM. Favre and Silbermann, and the theoretical evaporative power in pounds of water evaporated from a temperature of 212 degrees at atmospheric pressure :—

	Specific Gravity at 32° Fah.	Carbon.	Hydrogen.	Oxygen.	Sulphur.	Heating Power in Thermal Units.	Pounds of Water Evaporated from and at 212°.
Pennsylvanian oil, crude, heavy ...	0·886	84·9	13·7	1·4	...	20,700	21·428
Russian oil, light ...	0·884	86·3	13·6	0·1	...	20,372	21·607
„ „ heavy ...	0·938	86·6	12·3	1·1	...	20,102	20·81
„ petroleum refuse	0·928	87·1	11·7	1·2	...	19,794	20·49
Average of 98 samples of British coal ...	...	80·0	5·0	8·0	1·25	14,132	14·63

The combustible components only and oxygen of the coal are given in the table, the remaining parts are—nitrogen, 1·2; and ash, 4·55 per cent.

Taking the average theoretical evaporative power of the four samples

of oil at 21·1 lbs. of water, the oil has, tested by chemical composition, an advantage of 44 per cent. over the coal. The oils may be accepted as fair average samples, but the author's experience is that the theoretical evaporative power of coal, as usually delivered into ships bunkers, does not exceed 13½ lbs. of water per pound of coal, which further increases the advantage of the oil to 56 per cent.

Having investigated the evaporative performance of a considerable number of boilers from published data, and also from data obtained during experiments at which the author was present, he is satisfied that the average efficiency of the ordinary marine boiler is 70 per cent. of the theoretical evaporative power of the coal used, and therefore the actual evaporation from and at 212 degrees is $13\frac{1}{2} \times \cdot 70 = 9 \cdot 45$ lbs. of water.

The 30 per cent. loss is accounted for by loss of heat in gases passing up the chimney, but necessary to produce draught, from unburnt fuel remaining in the ashes, from unconsumed fuel passing away in the form of smoke, and from radiation.

Using liquid fuel there is no smoke, the oil is entirely consumed, and the only losses are from radiation and from the heat passing up the chimney, the latter loss being very materially reduced.

The perfect admixture of air and oil obtained by means of the spray injector, or pulverizer, renders air for dilution of the furnace gases unnecessary, therefore only about 15 lbs. of air are required per pound of oil, as against 24 lbs. of air per pound of coal, and the initial temperature in the furnace being greater, because of the smaller quantity of air required, the heat passes more rapidly through the heating surface to the water in the boiler.

There is thus a much reduced quantity of air to carry off heat, and more heat taken out of the oil gases on the way to the chimney than there can be taken out of coal gases.

The sources of loss thus minimised, it necessarily follows that a boiler, in which oil is being burnt, must have a much higher efficiency than when coal is used, and actual experience proves that the efficiency rises from 70 to 90 per cent., therefore $21 \cdot 1 \times \cdot 90 = 18 \cdot 99$ lbs. of water actually evaporated from and at 212 degrees per pound of oil, or 100 per cent. superior to coal. This result agrees with those obtained on the Caspian and Volga, where one ton of petroleum refuse is found to do the work of two tons of coal, and which has been experimentally proved in this district by Colonel Sadler, of Middlesbro', who has been burning both oil and tar in his company's works for a considerable period. When the author had the pleasure of visiting the works, in January last, two tons

of coal were required to do the work of one ton of oil, and the results then achieved have been fully sustained in continuous working up to the present date.

The work devolving on the stoker, on board ship, is very light. The steam connection with the donkey boiler is opened and all water cleared out of the pipes and spray injector, then a piece of burning waste, saturated with oil, or a quantity of lighted shavings is thrown into the furnace, when the steam jet and oil supply are gently opened, and the fine spray instantly ignites, the oil supply is gradually increased until the required quantity is being consumed, and the air supply is regulated until a clear white light is produced.

This attained, with steam from the main boilers, it is generally found unnecessary, in the case of steamers running from Baku to the mouth of the Volga, to interfere with the burners again during the voyage, which is usually of two days' duration.

The nuisance, on board steamers, of cleaning fires, and getting up ashes every watch is entirely abolished, and the small amount of attention required, when the burners have been adjusted, renders unnecessary more than one attendant at a time in the stokehold, even for a considerable number of furnaces.

When it is found necessary during a voyage to lie, as it were, "under banked fires," a brick is frequently placed a short distance from the nozzle and just sufficient oil injected to keep the one brick red hot, so that when full steam is wanted the brick serves to ignite the spray during the short period required to render the entire brick furnace incandescent.

The most important appliance to be considered, in burning liquid fuel, is the spray injector or pulverizer, and a large number of designs have been tried with more or less satisfactory results. Three, of what may be considered typical forms, have been selected for description and illustration.

1st.—Brandt's apparatus, Fig. 1, Plate I., which consists of a casting in which two independent passages are provided, with a separate branch to each passage, the one for the admission of steam and the other for oil. On the end of the casting next the furnace a circular cap is screwed, covering both passages, and in this cover a conical valve seat is formed; the conical valve is held in its seat by a screwed spindle, which affords a subsidiary means of regulation, the main regulation being effected by the two cocks fitted in the steam and oil branches. Both cocks being opened, the oil is drawn through small openings near to the conical valve

by the action of the jet of steam and injected in the form of a fine conical spray to the furnace. The air supply is provided apart from the apparatus by openings in the furnace front. Figs. 2 and 3, Plate I., show the mode of application to the furnace.

2nd.—The burner, patented by Colonel Sadler, which is probably the simplest pulverizer known, and by means of which excellent results have been obtained. (Fig. 4, Plate II.)

This apparatus is of the injector type, and consists of two small brass cones, male and female, screwed into a wrought iron T-piece, one at each end. The stem of the T is turned upwards, and a second T-piece is fixed to it; the oil supply pipe is attached to the horizontal branch of this T-piece, and the vertical serves to admit hot air. The steam supply pipe is carried into the furnace and formed into a coil or circle through which the steam passes, and is super-heated before entering the burner through the male cone. The oil and air flowing into the burner through the same passage, and being forced through the second cone by the super-heated steam, a thorough admixture is secured. Figs. 5 and 6, Plate II., show the mode of application to the furnace and the arrangement of the brickwork adopted by Colonel Sadler.

3rd.—The recently patented improved apparatus of Mr. Thos. Smith, Cullercoats, Fig. 7, Plate III., in which the supplies of steam, air, and oil are all regulated by provisions in the apparatus itself. The facilities for external regulation constitute the principal difference between this pulverizer and several others in use. It consists of two concentric tubes, the inner tube being screwed, and its position adjustable with respect to the outer tube, and also a central screwed spindle, to which a conical valve is attached, the spindle with its valve being adjustable with respect to the inner tube. The oil and air enter the apparatus by the same pipe, and pass through slots into and flow along the inner tube to the conical valve, while the steam passes into the annular space between the two tubes at the end next the furnace. A mitre is formed in the end of the inner tube which forms a seat for the conical valve, and when the central spindle is revolved in the proper direction oil and air are admitted to the furnace. Similarly, the the exterior of the inner and interior of the outer tubes act as valve and seat, and when the inner tube is caused to revolve steam is admitted, and the supplies of steam, oil, and air are all regulated at the point where they are injected to the furnace. An outer cone, also acting as a valve, is screwed on the furnace end of the outer tube, which may be screwed backward or forward, at pleasure, and any further supply of air which may be required admitted.

This apparatus is much more complex than the two previously described, but is not more complicated than several others in use, and its parts are so arranged that it may readily be taken to pieces and put together again. Figs. 8 and 9, Plate III., show the mode of application to the furnace, and the arrangement of brickwork preferred by the inventor. The author hopes shortly to be able to communicate the results of experiments made with this apparatus to the Institution, as arrangements have been made to thoroughly test its capabilities.

The result obtained with coal tar, as a fuel, about equals the performance of petroleum, but the arrangements and fittings up to the point of burning, are somewhat more elaborate than necessary, when burning oil.

At Colonel Sadler's works, the tar to be consumed was contained in a large tank, having a spiral coil within it, filled with live steam, to keep the tar in a thoroughly fluid condition. From the large tank the tar was allowed to run into a very small one, covered with a wire strainer, having 26 meshes to the inch, which cleared the fluid of all impurities likely to choke the injector nozzles. From the small tank the tar was conveyed some distance by a 2 inch diameter pipe, having a $\frac{1}{2}$ inch pipe containing live steam, running through it; and when the tar flowed into the tube leading to the burner it had the appearance and consistency of very dark, heavy petroleum, for which it proved an excellent substitute. The average analysis of the tars burnt at Messrs. Sadler & Co's. works are—carbon 91, and hydrogen 9 per cent., specific gravity 1·8, heating power, in thermal units 18,778, and water evaporated from and at 212 degrees, 19·44 lbs., according to the chemical constituents. The water actually evaporated is $19{\cdot}44 \times {\cdot}90 = 17{\cdot}496$ lbs. per pound of tar, or 85 per cent. superior to ordinary bunker coal.

There is another point connected with the burning of liquid fuel which demands consideration: the quantity of steam required to work the injector, and its probable effect on the boiler, owing to the necessity of making good the quantity of fresh water so abstracted by the addition of sea water.

In the case of a steam jet applied to produce draught, the best results are obtained with steam at maximum pressure, but in burning liquid fuel, only sufficient pressure is required to pulverize the oil into a fine spray, probably not more than 10 lbs. per square inch; but, supposing 20 lbs. per square inch is required, a nozzle $\frac{1}{8}$th of an inch diameter will discharge about 600 lbs. at that pressure in 24 hours into the open air without doing work. In oil burning, however, the energy is taken out of the steam in doing work on the oil which it carries into the furnace,

and the flow is consequently greatly retarded, so that probably not even the half of 600 lbs. is used, and should this small loss be deemed objectionable, it may be entirely obviated by using compressed air. It is hardly possible to conceive of the engineers in the Caspian, the largest salt water lake in the world, having a strong preference for liquid fuel if the boilers were speedily salted up and injured; nor is it probable that the increase in oil burning steamers would have proceeded with such rapidity if this had been so, as it would have taxed the pockets of owners too heavily.

There were, in 1884, about 300 steamers of various sizes, many of them small, running on the Volga and Caspian, burning solely petroleum or petroleum refuse, and on the South Russian railways not less than 100 locomotives fired with the same fuel.

Judging from the handiness with which liquid fuel can be manipulated, from its smokeless character, from the facilities it affords of maintaining steam at full power for any length of time, or rapid adjustment to any power which may be required, there is probably no fuel better adapted for the requirements of ships of war. Indeed, the Russian Government had been experimenting with it, for some years previous to 1884, on the Caspian, and, at that time, were so satisfied with the results obtained from the 10 or 12 vessels and gunboats, that they had then taken steps to fit up several vessels on the Black Sea, chiefly torpedo boats, for which this fuel was considered eminently suited.

The problem before us, then, until some petroleum area has been opened up nearer home, is to strive to devise such structures as will best serve to cheapen the cost of transport, in order that we may avail ourselves to the utmost, in commerce and industry, of this valuable natural product, and this problem will be dealt with in the following part of the paper.

HAVING been requested to supplement the very interesting paper by our friend Mr. Nichol, to which we have just listened, with some remarks on the arrangements required for safely carrying on board ship liquid fuel in bulk, and having had the opportunity, in the capacity of Surveyor to the Bureau Veritas, of inspecting the most recently constructed ship for the carriage of petroleum in bulk, viz., S.S. "Glückauf," during her entire construction, and again quite recently on the completion of her first voyage, the author trusts that some description of her arrangements and

their practical effect may not be without interest. Mr. Nichol, as an engineer, has pointed out the immense economic value of liquid fuel, as compared with coal in its calorific effect, its great superiority to coal for steamships in the reduction of labour in firing, in avoiding the necessity for cleaning fires and tubes, in the absence of ashes and scar, and in its requiring no trimming in bunkers. It also possesses special advantages in the promptness with which steam can be got up, and the facility with which the production of steam may be increased in emergency, or instantly diminished almost at will, in the absolute closeness of its stowage, and its adaptation for conveyance in such parts of the vessel as are, from their shape, not available for any ordinary description of cargo. To all these advantages if we add extreme facility and small cost of shipment, also simplicity of measurement, it would appear that even at a considerably enhanced price, as compared with coal, mineral oil should be adopted whenever it can be obtained, as fuel for steamers.

There is, however, a prejudice against the use of liquid fuel, arising from the idea that it is not easy to make compartments tight enough to carry mineral oil in bulk, some shipowners being much affected by vague fears of explosion from leakages and gases, which, on account of their vagueness, are very difficult to meet.

The influence of prejudice is clearly shown in the facts brought out in a very able, and (at its date) exhaustive paper read by Mr. B. Martell, on the 27th July last, at Liverpool, before the Institution of Naval Architects. He showed that many years ago the idea of carrying mineral oil in bulk was before the public; but after all these years the old and dangerous method of carrying it in casks has survived, and keeps its hold on the bulk of the American trade at this moment, while the efforts at emancipation from the cask monopoly have given rise in succession to the tin-lined case, the small tank, the larger tank, the double-skinned ship, and at last to the most rational arrangement of all, the conveyance of the oil directly against the bare skin of the ship, without tanks and without extraordinary precautions of any kind. The author will not recapitulate the details which have already been so ably given by Mr. Martell, but rather bring before your notice some small personal experience gathered since that paper was read.

The saving derived from carrying petroleum in bulk is an accepted fact. A vessel similar in size to the "Glückauf" would take from three to four weeks to load a cargo of oil in casks, but with her present arrangements for carrying it in bulk, she can be easily loaded in three days, and even this comparatively short time might be much shortened if necessary. Again: the vessel now carries a sufficient quantity of oil to

fill 23,000 barrels, whereas a vessel of exactly the same dimensions, specially built to carry petroleum in casks, could not stow more than 12,120 barrels—about 52½ per cent. of the quantity carried in bulk.

It is hardly requisite to discuss the prejudice which exists against the carriage of oil in bulk when compared with its carriage in casks on the score of safety. Of course, it is necessary to take some precautions. For instance, it is important to avoid frothing the oil by allowing it to fall from a height into the receptacle provided for it, and likewise to avoid the churning action which would be produced by the movements of the ship if the compartments were only partially filled, both of which tend to produce gas and deteriorate the oil. It is necessary that the structure and workmanship of the compartments should be of a high class, so as to prevent leakage; and if leakage should occur, that it be confined to parts of the ship out of reach of the boiler fires. A provision is required to keep the compartments full, notwithstanding the contraction or expansion of the oil by change of temperature at sea, also for allowing the escape of any small quantity of gas which may be generated, and for the ventilation of empty spaces in the neighbourhood of the oil tanks where gas could possibly accumulate. But comparing the facility with which all these matters can be provided for in a ship carrying oil in bulk, with the difficulty, or impossibility, of doing so in a ship carrying oil in casks, it seems quite clear that if the present innovation was to substitute cask carriage for bulk carriage, the outcry against it would be unappeasable. The cask must not be filled quite full or it will infallibly leak, and any leakage would necessarily run through the whole cargo and bilges. The ullage of the cask thus inevitably makes some churning action. The structure and workmanship of the casks must be of a high class to hold oil at all, and represents a cost equal to from one-third to one-fourth of the value of the oil carried. It will thus be seen that every consideration of safety demands carriage in bulk.

The great initial difficulty in the way of constructing such vessels was the objection made to the single skin on the question of classification. The Bureau Veritas Society, however, was satisfied that a vessel could be properly constructed to carry oil out to the skin, and encouraged that system, which now proves to be a success.

The S.S. "Glückauf" is a steamer which has been built for this special trade, to run between the petroleum ports of America (or the Black Sea) and Germany. She is the first of two sister ships built by Sir W. G. Armstrong, Mitchell, & Co. The hold is divided by a middle line longitudinal bulkhead, and further sub-divided by thirteen transverse bulkheads; eight of these compartments are intended to carry oil. At

the fore end there is a compartment for water ballast, and water ballast tanks are also fitted under the engines and boilers. At the fore part of the engine room there are two bulkheads, spaced 4 feet apart, intervening between the engines and the cargo. This compartment, or well, is for the purpose of receiving any oil which might leak from the cargo compartments or trunkways, and may be kept as an empty space, having provision by which it may be cleared of gas at any time by a steam jet. Each oil compartment is fitted with a trunkway, running up to the upper deck, forming a self-acting feeder to the main compartment as the temperature diminishes, and allowing the liquid to expand if its temperature should increase.

The "Glückauf" arrived on the 22nd August at Geestemünde with her first cargo of best refined oil from New York. The oil was found to be in excellent condition in all respects, and gave the highest satisfaction. From the refinery at New York the oil was run into the vessel at a temperature of 87 degs. F. On her arrival at the port of discharge, after sixteen days' voyage, the temperature was found to be reduced to 67 degs. F. The contraction of the oil due to this reduction of temperature was 0·86 per cent.

Figs. 10, 10A, and 10B, Plate IV., give longitudinal, plan, and midship section of S.S. "Glückauf."

The arrangements of S.S. "Glückauf" are those patented by Mr. Henry F. Swan. Mr. Swan has also taken out a patent for another description of vessel, specially intended to carry a large amount of water ballast without its being necessary to utilise for this purpose any of the compartments intended for containing oil. If this were done by making the inner bottom flat, in the ordinary way, to contain a sufficient amount of water (say one-third of the vessel's cargo capacity), the result would be, that the centre of gravity would be so low, that the vessel, when in ballast, would be a very bad sea-boat, and when laden with oil, the centre of gravity, on the other hand, would be too high. To meet these points, Mr. Swan makes the inner bottom in an inclined form, either as per section, Fig. 12 or 12A, Plate V. Either form gives all the advantages of an ordinary double bottom, but in many respects the form Fig. 12 is preferable, and it will be observed that unusual facility is given for repairs and examination, as a man can freely walk about in an upright position, instead of having to crawl through very irregular spaces as in the ordinary double bottom, and which, if gas had accumulated, might become positively dangerous. (Figs. 11 and 11A give longitudinal section and plan of these vessels.)

In case the inner bottom has been utilised for carrying crude petro-

leum, or if from any other cause, gas has accumulated, the same can be entirely got rid of by simply pumping up the inner bottom, and continuing the pumping up the trunkways, which are open to the upper deck, and which form a means of access to the interior of the vessel at all times.

The author may be allowed to say that, though it must be admitted it was a somewhat bold undertaking upon the part of the owners of the "Glückauf" to order this first vessel, yet the merit of her success rightly belongs to the eminent firm of shipbuilders in whose yard she was constructed.

The sister ship, now building by Messrs. Armstrong, Mitchell, & Co., is constructed on the same principle as the first. There is no cement in the bottom of these vessels in the way of oil, the oil filling the floor spaces.

Messrs. R. & W. Hawthorn, Leslie, & Co. have now in course of construction two vessels for this particular trade, one of which is being built under the Bureau Veritas' special survey. (See Figs. 13, 13A, 14, and 14A, Plate VI.

These vessels are constructed with a double bottom, so that all the oil-tight work being done on straight and almost plain surfaces, in case of injury to the ship's bottom, the necessary repairs can be as easily executed as on an ordinary vessel. Fore and aft bulkheads are fitted throughout the oil compartments, and where there is only one bulkhead, a suction is fitted to either side to correct a list in loading or discharging.

In one design (Figs. 14 and 14A), in order that two kinds of oil may be carried, the holds are divided amidships by a 4 feet space, which also serves to carry up the trunks for access to the double bottom.

In the double bottom, transversely there is a slight rise to cause a run to the suction and to facilitate the clearing out of air and gas when the ballast is being run up, as the air pipes are at the side on the highest part.

The expansion trunks are built on the deck. Perforated plates are fitted to prevent the oil moving in a body, and at the same time to allow it to expand into the hatch. Small air pipes are fitted to the hatch covers; these may be closed when desired so as to give some control over the escaping gases.

The pumps on both these vessels are placed right forward and on the tank top, as it has been found difficult to lift petroleum any great height in hot weather, owing to the low tension of its vapour.

Fig. 15, Plate VII., shows the midship section of the ship "Andromeda." This vessel was lately fitted with tanks in order to carry petroleum in bulk. She has made one or two voyages successfully, and delivered her cargo in good condition. This system does not (to the author's mind) compare favourably with that of carrying the oil out to the skin of the ship.

The author, in Fig. 16, Plate VII., submits to this Institution a plan of dealing with old vessels, to adapt them for the carriage of this liquid, which, he considers, will overcome some of the difficulties met with. The form of the ballast tank top, he believes, is similar to the principle adopted by Mr. H. F. Swan. The sides of the oil compartment are made to form an inner skin to the ship, allowing a space between them and the skin to admit of easy access to all parts of the tank for erection or any necessary repairs. By adopting this plan, he thinks there will be a considerable saving in the first cost as compared with fitting tanks, and it will certainly make a far superior job, as the carrying of the oil would entirely depend on new work, and further, the strength of the ship would be considerably increased.

Messrs. Boolds, Sharer, & Co., of Sunderland, have recently built two small steamers for Russia (Figs. 17 and 17A, Plate VIII.), fitted for the conveyance of oil in the bunkers as fuel for the ship's own use. The bunkers were fitted in part of the main hold, and also in the engine and boiler space—the bunker compartments extended to the skin of the ship, and were fitted on deck with manhole doors instead of hatches.

There can be no doubt that for marine propulsion, and especially for ships of war, petroleum or mineral oil as fuel will be extensively used when more experience demonstrates its advantages as compared with coal, and the author looks to see tank hulks established at coaling stations, and its use restricted only by the limited supply.

It may be interesting to the members to give an idea of the arrangements at Geestemünde for discharging and storing the oil. This is shown on Plate IX. A flexible pipe is jointed to the ship's side and reaches to a pump driven by a gas engine on shore. The engine house is marked A. The pump delivers into the circular tanks marked Nos. 1, 2, and 3. The combined capacity of these tanks is 4,900 tons. The house marked G is the weighing house, where railway tank trucks are both filled and weighed. The railway trucks are like our ordinary tank trucks, and hold about 12 tons of oil. The oil is sent in these trucks to the interior, or to any point in the railway system of the continent, and it is then unloaded into tank carts, holding each about a ton, from whence it is retailed into the tanks of storekeepers or private customers. It is not intended that the oil carried in bulk should be casked at all, although, of course, for special cases this may be easily done.

To illustrate Messrs. B. G Nichol & J. Gravells' paper "On the Use & Transport of Liquid Fuel."

FIG. 1.

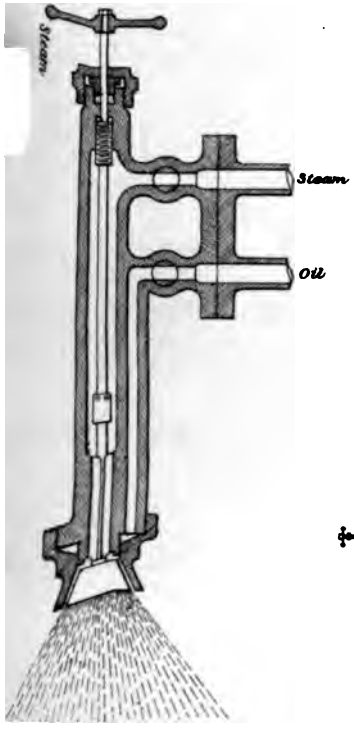


FIG. 2.

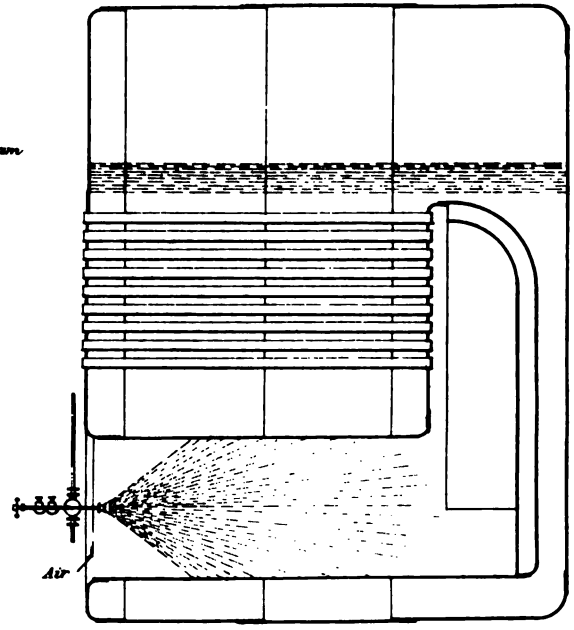
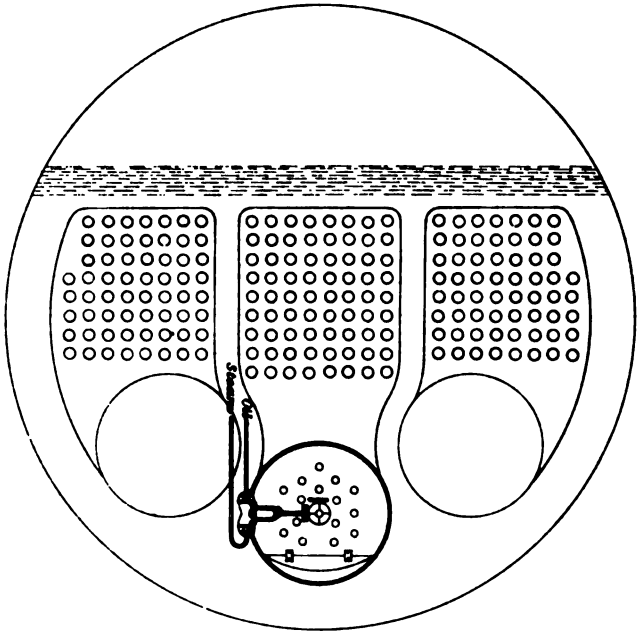


FIG. 3.



To illustrate Messrs. B. G Nichol & J. Gravells' paper "On the Use & Transport of Liquid Fuel."

FIG. 4.

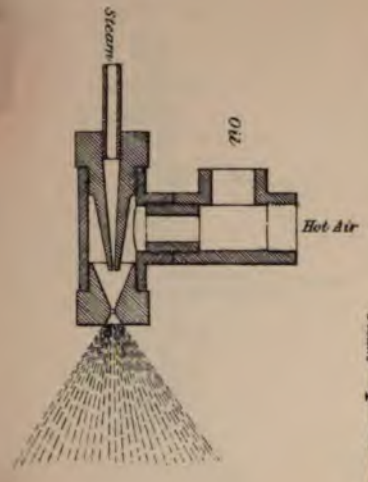


FIG. 5.

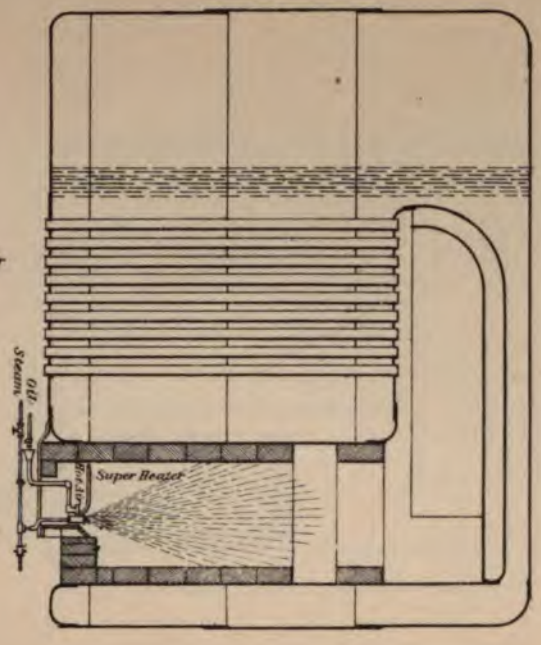
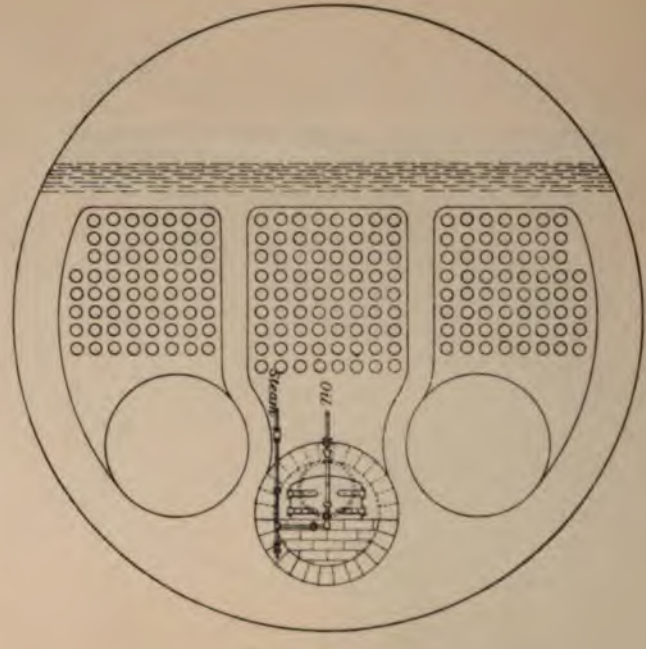


FIG. 6.



To illustrate Messrs. B. G Nichol & J. Gravells' paper "On the Use & Transport of Liquids"

FIG. 7.

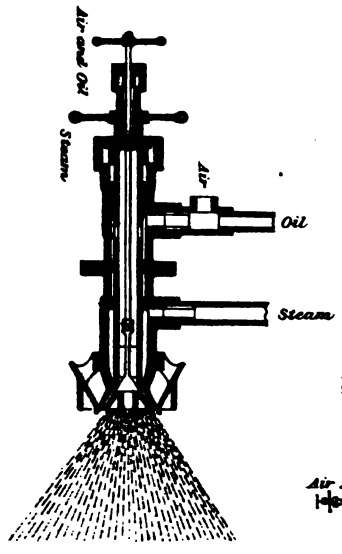


FIG. 8.

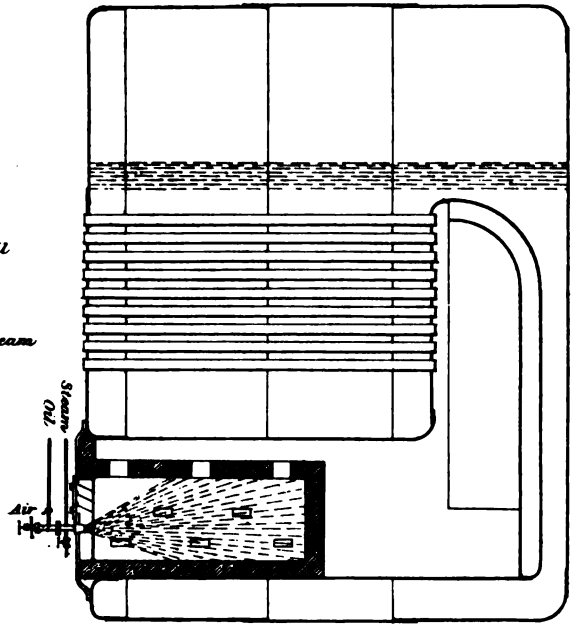
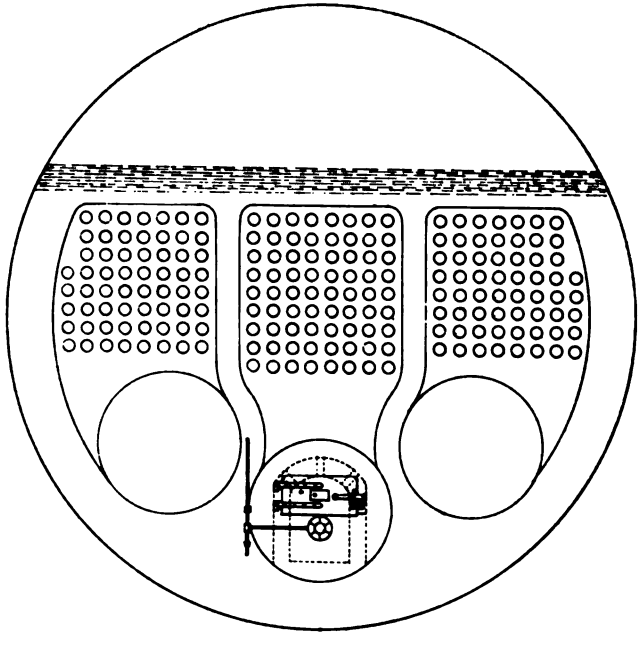


FIG. 9.



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To illustrate Messrs. B. G Nichol & J. Gravells pa

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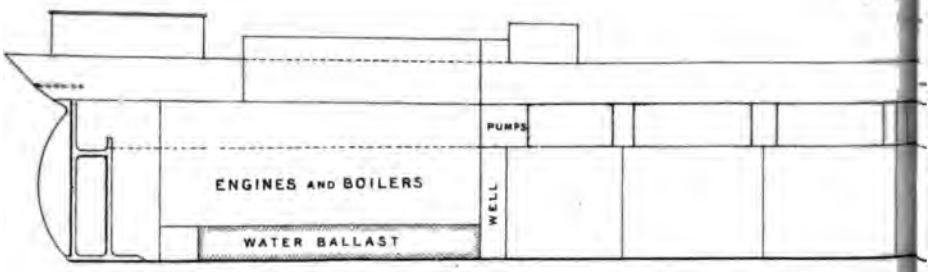

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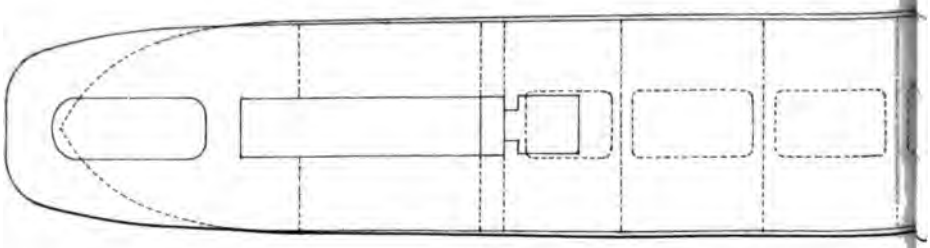

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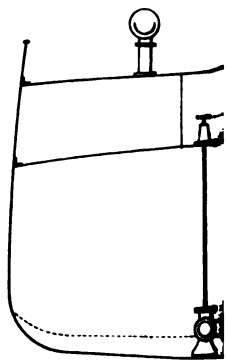

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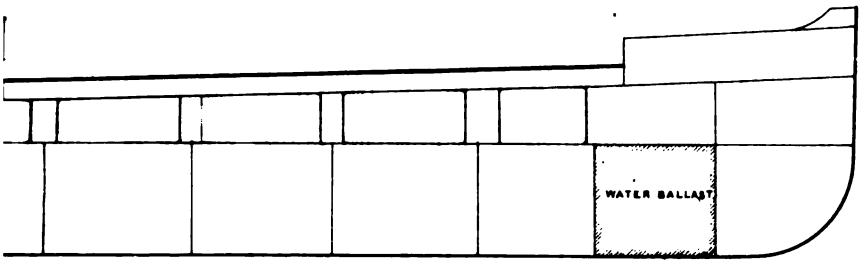

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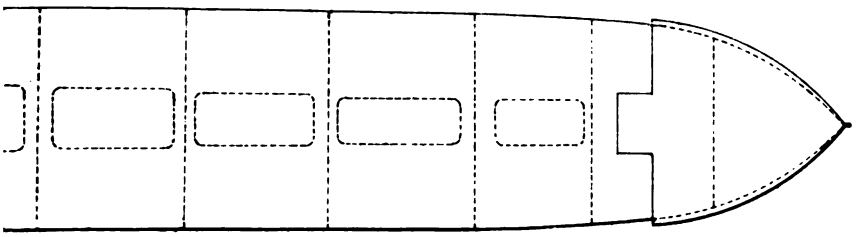

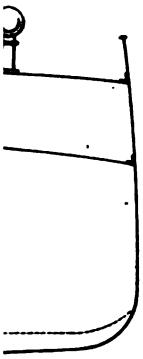

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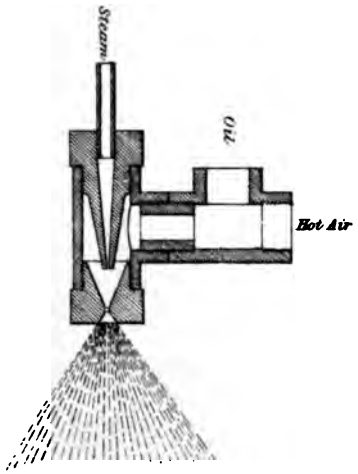
FIG. 4.



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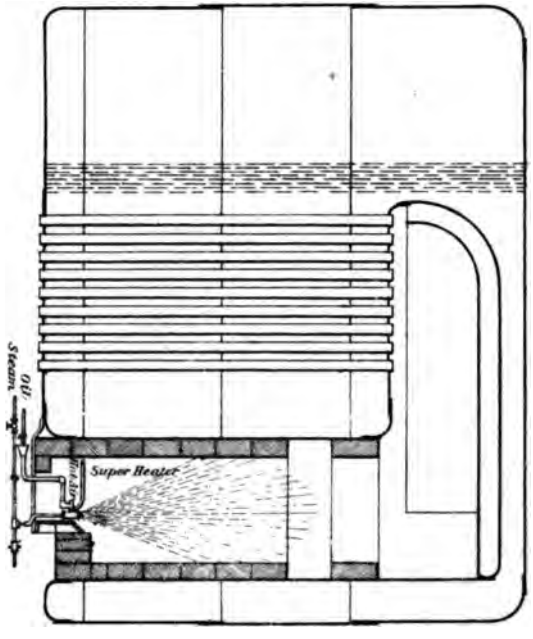
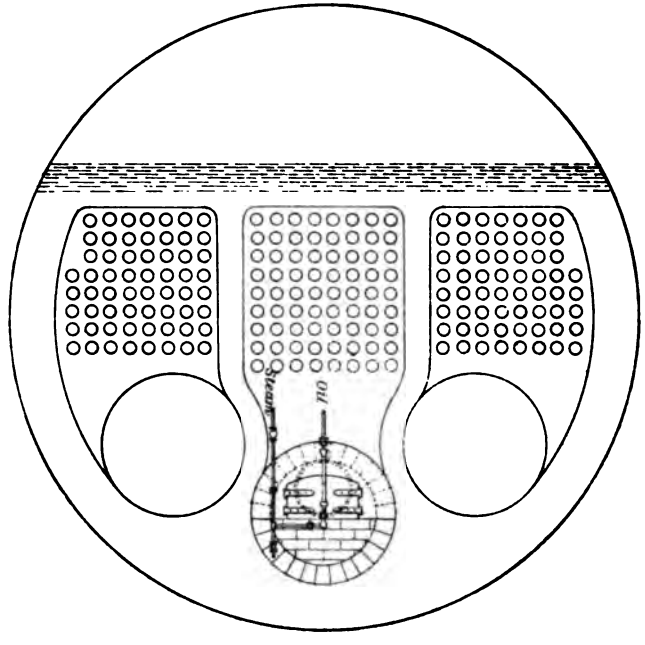


FIG. 6.



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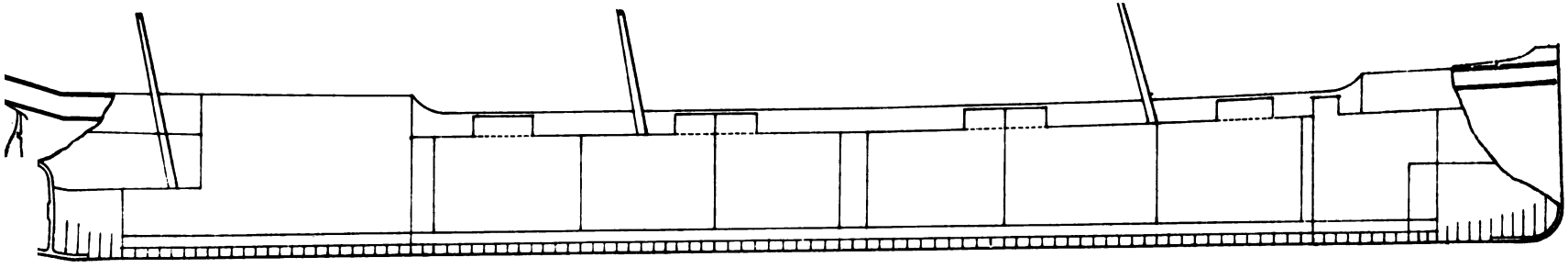
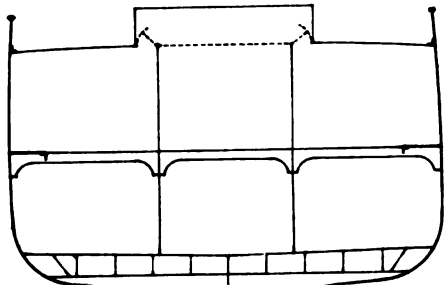


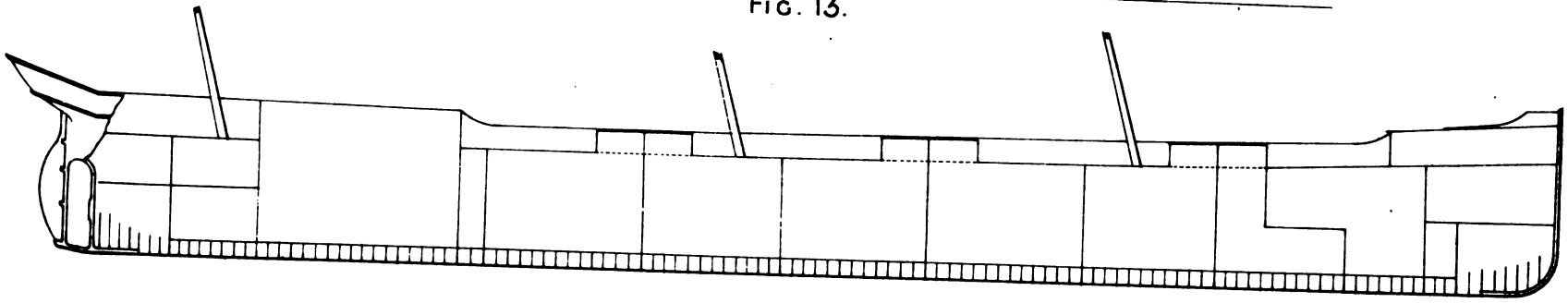
LONGITUDINAL SECTION.

FIG. 14A



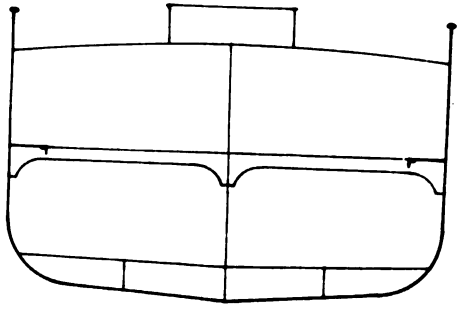
To illustrate Messrs. B. G Nichol & J. Gravells' paper "On the Use & Transport of Liquid Fuel."

FIG. 13.



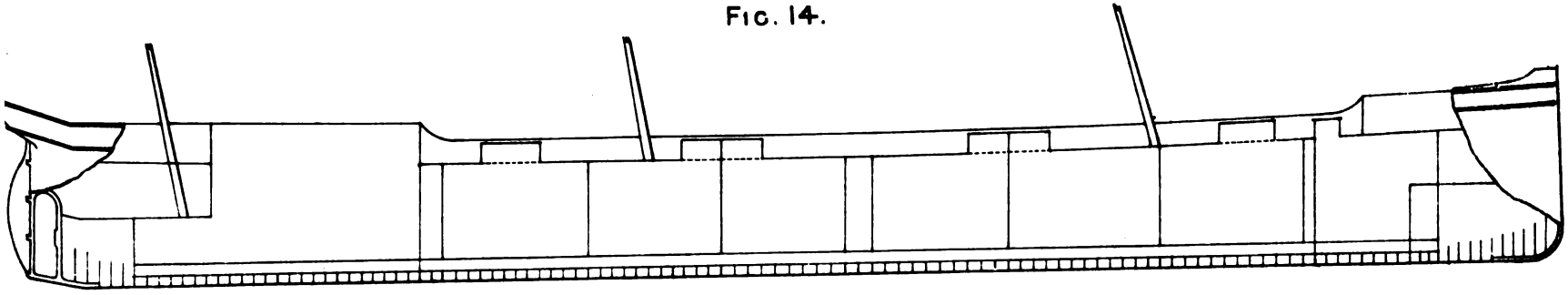
LONGITUDINAL SECTION.

FIG. 13A



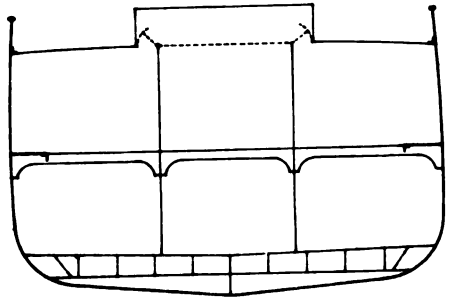
MIDSHIP SECTION.

FIG. 14.



LONGITUDINAL SECTION.

FIG. 14A



To illustrate Messrs. B. G Nichol & J. Gravells' pa

FIG. 15.

SHIP "ANDROMEDA".

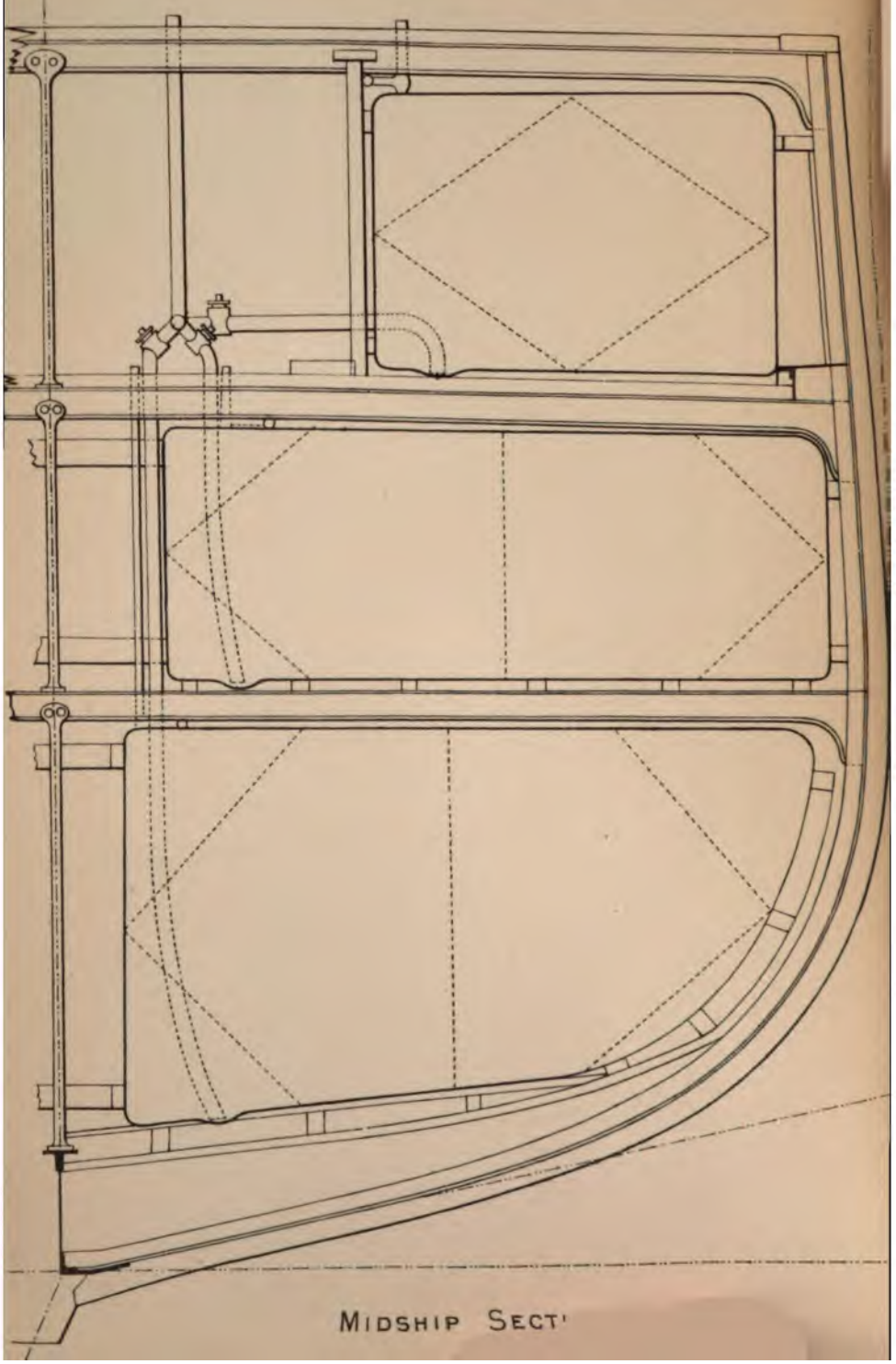


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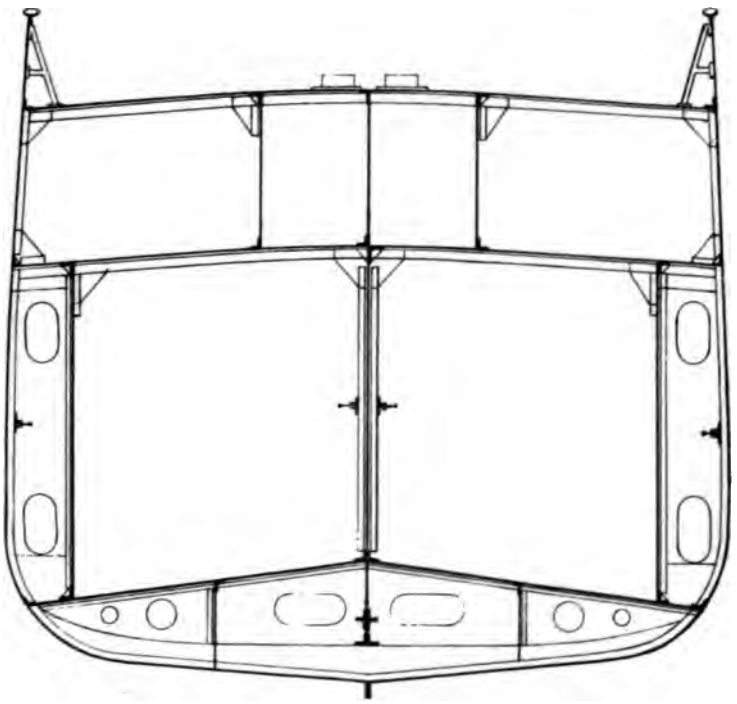
FIG. 16.

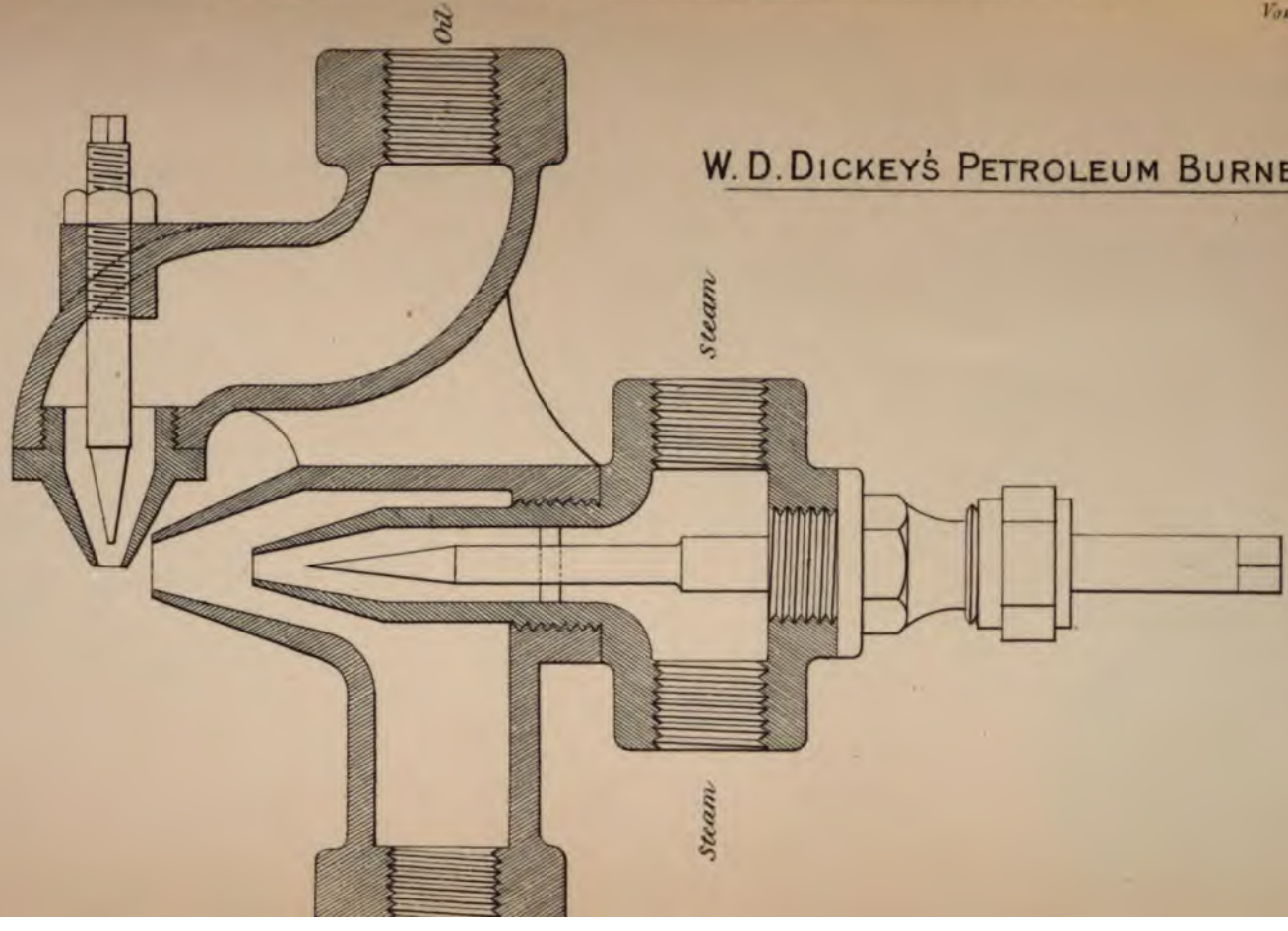


MIDSHIP SECTION.

To illustrate Mr D Andrew's remarks upon Messrs. B. G. Nichol and J. Gravell's paper.

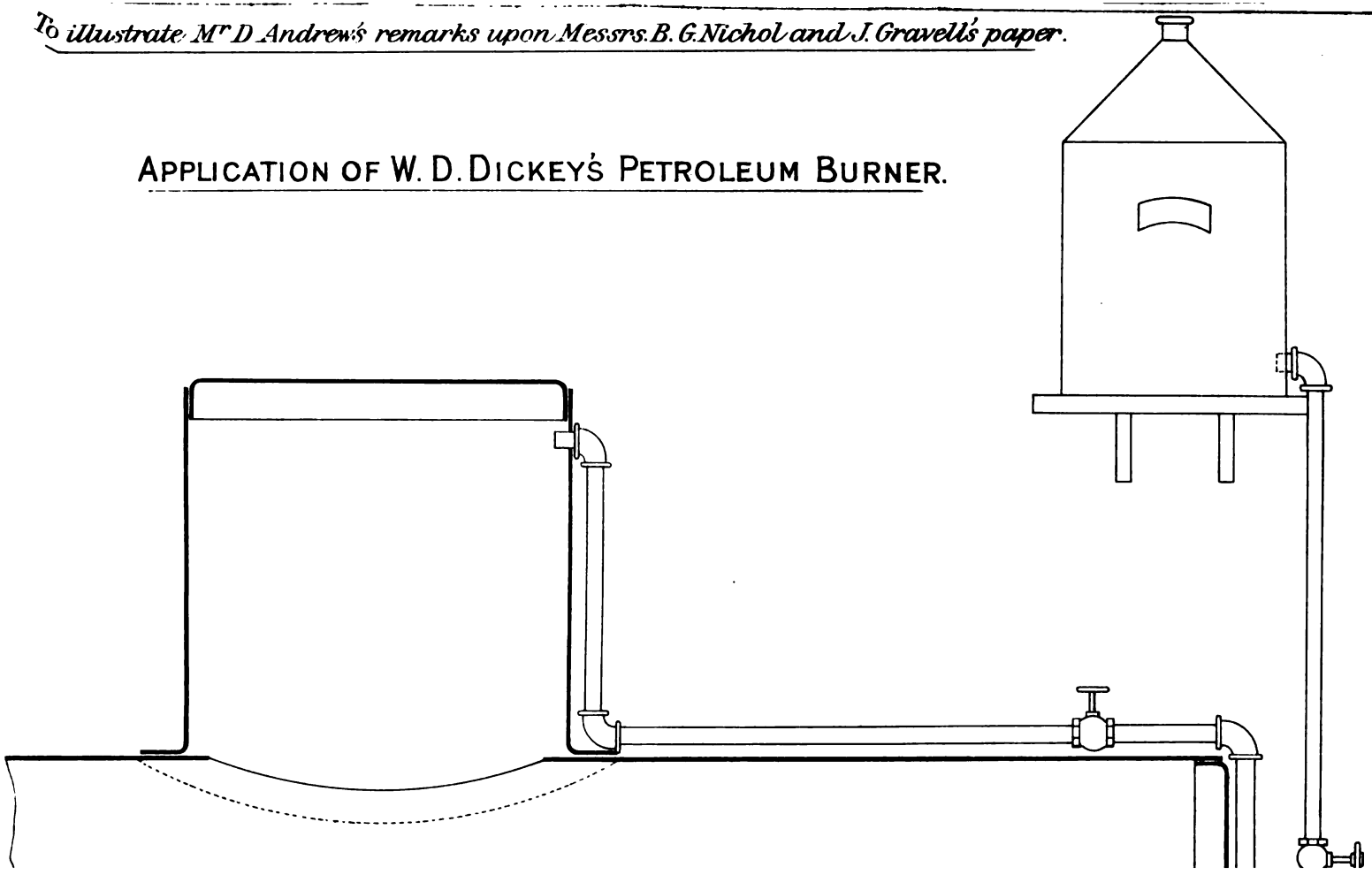
Vol. III Plate 10.

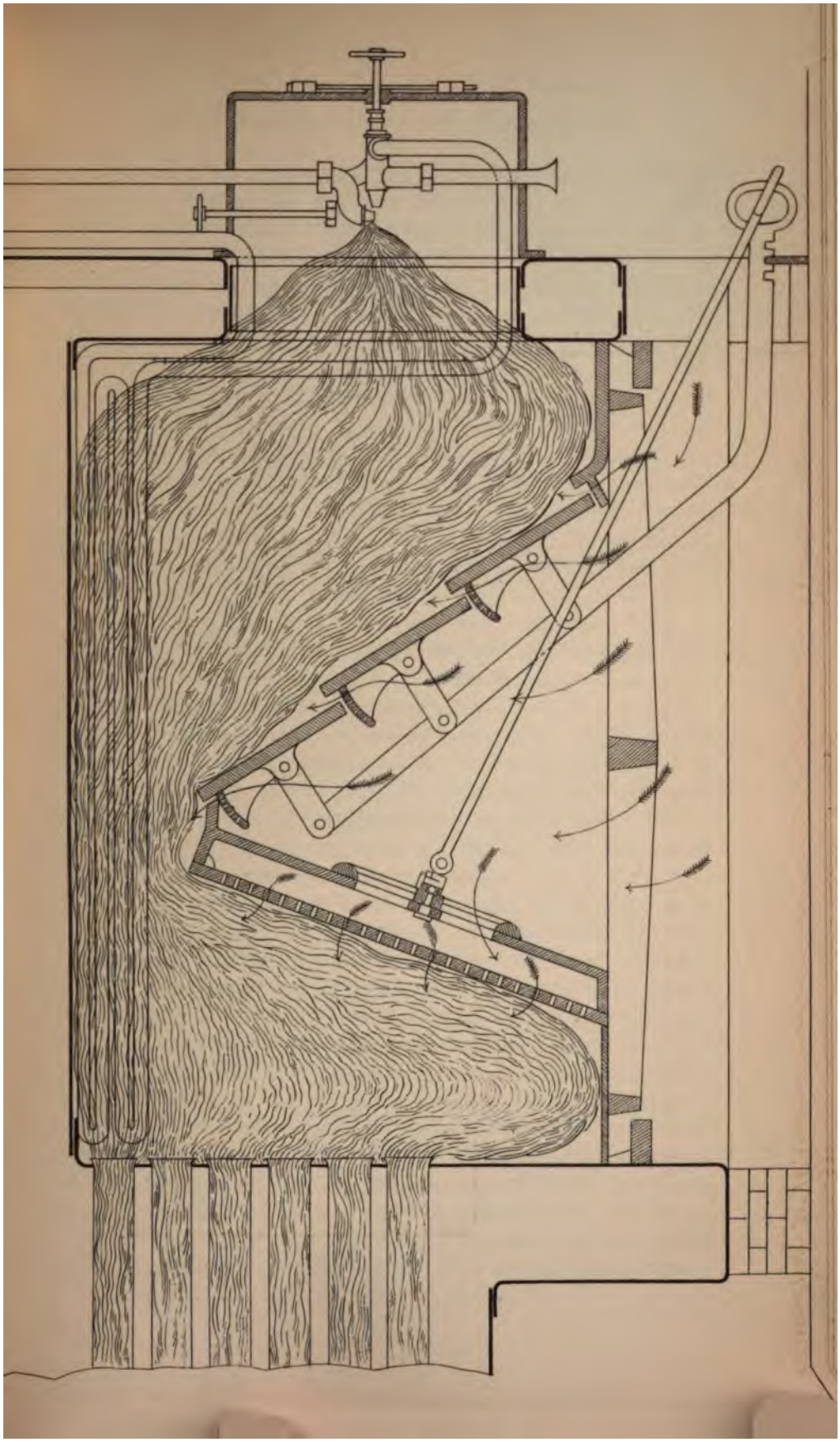
W. D. Dickey's Petroleum Burner.



To illustrate Mr D Andrew's remarks upon Messrs. B. G. Nichol and J. Gravell's paper.

APPLICATION OF W. D. DICKEY'S PETROLEUM BURNER.





Mr. H. F. Swan said, with due deference to the President's ruling, he thought that as the first part of the paper was more particularly connected with the consumption of petroleum, some engineer ought to have opened the discussion. However, on that subject, he could only say that for a dozen years or so his firm had been in the habit of building vessels for the Volga and Caspian, which were fitted with petroleum burners—none of them exactly as shown on the diagrams—but which had been entirely successful, and there was no question, if the supply of liquid fuel could be obtained, it would become the fuel of the future, although he thought they were a great many years from seeing that becoming the rule, because for general trading it would be necessary to have a system of reservoirs throughout the whole of the trading area. This would come in time. He believed they were on the eve of a very important addition to the general petroleum supply, as the Russian Government intend at once to grant a concession for a pipe line, which will give a large supply at Batoum, and as soon as that comes about a great impetus will be given to the consumption of liquid fuel. As regards the carriage of liquid fuel, he thought the paper had covered the whole ground. Of course, people were naturally inclined to have some prejudice in favour of their own arrangements. He could only say that he had studied the matter very carefully, and without saying that his (Mr. Swan's) plan was the best, he believed it would successfully carry out what was claimed for it. Either of his plans, with the inclined double bottom, possessed all the advantages of an ordinary double bottom, with the addition of giving the means of carrying a large amount of water-ballast and making the outer skin of the ship easily visited in the case of damage. It might, perhaps, be at times convenient to carry crude petroleum or fuel in the double bottom, for which the inclined form gave great facility. His firm found in the case of the "Glückauf," that when the compartments had been filled with water for the purpose of expelling a little oil that had been left there, that the oil simply rose and fell with the water, and could not be pumped out; but in the case of the conical bottom any oil would float on the top of the water, and by continuing pumping it would be expelled up the trunkways, and the compartment completely cleared. The plans which Mr. Gravell showed for converting old vessels seemed to be very good, but he was inclined to think that plan, Fig. 16, Plate VII., would be the more easily carried out, as it would leave a greater amount of the old part of the ship untouched, and, consequently, less of new work to be added; but either of the plans would make a very satisfactory arrangement. The subject was a very interesting one, and

he had no doubt but that some of the members would be able to give them some further information.

Captain McNabb said, he did not mean to speak on the scientific or technical points involved in the paper read, but would like to say something on the commercial part of the question from the shipowning point of view. He believed he was the first in this country who made a contract for the conveyance of oil in bulk from the Black Sea, and he had made a great many charters for the carriage of petroleum in barrels. He found the average carrying capacity of steamers employed in the conveyance of petroleum in barrels to be about 7·5 per net register ton, varying according to type and dimensions, the well-deck or single deck being the best; the worst being the double deck three tier of beams vessel, the range being from 6·5 to 9·5, and even as high as 10 barrels per net register ton, including deck load. A vessel, such as the "Marquis Scicluna," in which he was interested, because she took over the charter he had made for one of his own vessels of like kind, would carry about 9,500 American barrels; and trading between the Adriatic and Black Sea, to which he would prefer to confine himself for purposes of illustration, taking empty barrels from Fiume to Batoum and full back, would require for loading and unloading—four operations—some 37 days. There would be at least five Sundays involved, and the time occupied in steaming from port to port, two trips 20 days, making 62 days in all. Such cargo, 9,500 barrels, would be equal to about 1,520 tons of oil, and including the barrels would be, with dunnage, equal to about 1,720, whereas the same vessel, as a tank steamer, carries 2,000 tons of oil in bulk, and will only occupy a maximum time of 27 days to perform the round voyage. With barrels at the present rate of freight the vessel would earn—empty out, full back—£2,060 freight each voyage, and he reckoned she would make five voyages in the year, making £10,300. The port charges, and loading and discharging expenses, on each round voyage would, he knew from actual experience, be about £230: this multiplied by 5 gave £1,150, or a net earning for the year, exclusive of wages, provisions, coals, stores, and insurance, of £9,150. The same vessel, carrying 2,000 tons of oil in bulk at the rate of 14s. per ton, would earn £1,400 each voyage, and performing the voyage, as previously intimated, in 27 days, including five days for loading and discharging, as provided by charter; and allowing 35 days in the year for docking, painting, repairs, and other possible causes for loss of time, the vessel would make 12 voyages in the year, this would make the gross yearly earnings £16,800. In the case of the bulk oil steamer, instead of the

port expenses for the two ports on each round being £230, they would actually be about £70, or for the 12 voyages £840. This deducted from £16,800 leaves £15,960 for the net earnings of the year, as against £9,150 for shipment by barrels, or, in favour of the tank steamers, £6,810 per annum. That being the case, he was anxious, and would very much like to see our shipowners and merchants go into the trade freely and vigorously. He could not see why foreigners should be allowed to have a monopoly of the trade, or why our merchant princes should not identify themselves with a trade in which the Rothschilds freely took a part. As to the advantages to the merchant—the cost of the oil (he had it from a merchant) was, delivered on board ship, about £1 per ton; the cost to the merchant would be in the case of the tank steamer, £2,000; freight, £1,400; or at the port of delivery, £3,400—equal to £1 14s. per ton; and carried in barrels, it would be—cost, freight, and handling the barrels—£4,055, or £2 14s. per ton of oil, a difference of £1 a ton in the price of the oil at port of discharge. He would just like to say a word or two in reference to Mr. Gravell's paper before closing. When he made the contract, one and a half years ago, he was anxious that Lloyd's should support or give their sanction to such alterations as might be necessary to adapt existing vessels for the purpose of carrying the oil in bulk as tank steamers, and he waited on the heads of that society at London, pointing out how he proposed to adapt them. He was met with a *non possumus*. "Oil could not be carried against the skin or shell of a vessel; that only a double shell, such as that of the 'Svet,' or separate and independent tanks, separately constructed outside of and placed inside the vessel, the same as the 'Ferguson's,' should be thought of. You must have access to the shell of the vessel for the purpose of examination and repairs; you must provide against leakage through bulkheads, and against fire from gases," etc., etc.; all of which had been amply and perfectly provided for by his plans. His explanations and his pleadings were of no avail. The "Chigwell," the "Marquis Scicluna," and the "Petriana" have been altered and adapted, and the "Bakuin" has been built as nearly as possible on the plans he first proposed, and Lloyd's have now apparently sanctioned the alteration and construction of vessels to carry oil in bulk against the shell. When he saw Mr. Martell in London, he (Mr. Martell) was utterly opposed to the scheme. How far that gentleman's modification of opinion is due to the persistent energy of Mr. Gravell, and the intelligent appreciation of the importance and simplicity of the subject by the Bureau Veritas, he could not say, but would leave his practical audience to draw their own conclusions.

Mr. D. ANDREW said, he had listened with pleasure to the paper just read by Mr. Nichol, he having become interested in the subject of oil as fuel when in New York six years ago. It was then commanding a great amount of attention throughout America, and a company called the Great Western Hydro-Fuel Company had been formed at that time to work a process patented by Mr. Dickey, of New York, about the year 1878. Several factories were then run, to use a Yankeeism, with oil upon Mr. Dickey's system. His burner is similar to those shown, being of the injector type (see Plate X.), but his furnace is somewhat different (see Plate XI.). About the year 1881 a locomotive on the Long Island Railroad was fitted to burn oil as fuel—an account of the apparatus, mode of working, and the trial trip, taken from the *New York Herald*, is given on page 51. He (Mr. Andrew) was of opinion that the only drawback to the use of oil on board steamers as fuel was the bunkering of it. If the present side bunkers and tanks under the engines and boilers were utilised for that purpose, when they became used down, the oil would be churned by the motion of the steamer in a seaway, and so create gas, deteriorating the oil, as stated by Mr. Gravell in the paper (page 35). So far as the burning of oil is concerned, it is an accomplished fact that oil can be burned in boiler furnaces, either marine or land, with great economy ; but the difficulty of carrying it in bunkers was a subject worthy of their consideration. He thought the danger arising from gas generated by the oil was a great drawback to its carriage in bulk, also to its use as a fuel, Still this gas might be utilised by passing it into the boiler furnaces and for the purpose of lighting the vessel, which would make it still more economical, and would also tend towards safety.

Mr. GEO. N. ARNISON, jun., said, the previous speaker (Mr. Andrew) appeared to think that the practice was to use petroleum oil of a light character for fuel ; but this was not so. Astaki, *i.e.*, the dregs of petroleum, is the kind used, and owing to all the light constituent parts having been removed by distillation, there was little or no danger whatever, if any, of an explosion taking place when it is carried as fuel in the bunkers of a steamer. Astaki is not only heavier than crude or refined petroleum, but has less searching qualities, and the same care does not appear to be necessary to make ironwork oil-tight when astaki is only to be carried. In two small screw steamers, the "A. H. N." and "Cebah," having oil bunkers, the shipowners who were experienced in liquid fuel arrangements, were satisfied with the bunkers being rivetted and caulked as usual in water-tight work, and the bunkers being filled with water to

test the workmanship. The bunker sides were carried down to the shell-plating, intercostally between the floors. From Mr. B. G. Nichol's paper, it might be inferred *tar* was the actual form of liquid fuel used by Colonel Sadler at Middlesbrough-on-Tees and elsewhere; but on his (Mr. Arnison's) visit to the works of Messrs. Sadler & Co. (Limited), and the S.S. "Cobden," in December, 1885, the actual fuel being used was creosote oil, a *residuum* left after distilling the tar for the production of anthracine, quinone, and alizarine. Creosote oil being liable to crystallise below 120 degs. Fahrenheit, a half-inch steam pipe is placed in the centre of the oil supply pipe running through Messrs. Sadler & Co.'s works. He (Mr. Arnison) was of the opinion that in the paper, the evaporative power of liquid fuel had not been over-stated. In Mr. D. Kinnear Clark's "Fuel: its Combustion and Economy," petroleum is stated to have 27,531 units of total heat of combustion of 1 lb. of combustible, and for ordinary tar an equally good result has been claimed. Mr. Edwin Henwood, of London, who is at present arranging for competitive trials of liquid fuel and coal in his screw tug "Ruby," with which he intends running two long trial trips, on each occasion taking evaporative results, speed, consumption, and indicated horse-power, claims to have obtained as high a result in the S.S. "Ryde" as an evaporation of 41 lbs. of water per 1 lb. of liquid fuel—apparently accounted for by the utilisation of the hydrogen liberated from the steam used for injecting the oil. This evaporative test is certified to by an independent expert. He could scarcely agree with Mr. Nichol, that the form of injector was the principal factor in the arrangement of a furnace for a marine boiler using liquid fuel. It seemed to him that it was necessary to have a thorough utilisation of the heating surfaces, and that the supply of air should not be obtained simply through and at the furnace door, but that there should be some means of supplying air to the combustion chamber. With regard to the question of transporting petroleum in bulk, there were important considerations that shipowners should keep in view, *e.g.*, at the end of their charter of three or more years they might find themselves practically in the hands of the foreign oil merchants, and if they had to alter their steamers so as to adapt them for ordinary trading purposes, they would have to face a heavy expenditure. Further, a steamer like the "Glückauf," with her machinery aft, would never make such a useful and profitable general trader as steamers with their machinery amidships. He did not—but would like to—know what effect refined petroleum would have on the iron or steel forming the hull of the vessels. It was well-known that such oil was largely

used for washing down marine engines, but if it were allowed to remain on the surfaces, would not the iron pit? There did not seem to be any danger of that nature with astaki, as Russian shipowners went so far as to (in the case of the bunkers before alluded to) advocate the omission of the Portland cement on the bilges where the astaki was to be carried, having found from experience that it had no deteriorating effect on iron. As crude, and especially refined, petroleum is of a different composition to astaki, possibly the effects might be dissimilar.

Subsequently, in reply to Mr. Wigham Richardson, Mr. Arnison said, the present value of creosote oil was about 13s. per ton, while in December, 1885, it was 25s. per ton; but he feared if any large demand arose for the oil its market value would speedily rise.

Mr. T. Putnam said, some few months ago they (the Darlington Forge Co.) conducted some experiments upon a Lancashire boiler, using oil as a fuel. The injector they fitted to the boiler was somewhat like, if not indentical, with that shown in diagram No. 4, Plate II., and the oil, he believed, was creosote, such as Messrs. Sadler were using. The quantity required was about 120 gallons to raise the same amount of steam as raised by a ton of coal, and the only reason why they discontinued its use was obvious—the price did not compare favourably with coal. Could they have got the oil at the same price as coal per ton they would, most unhesitatingly, have used it throughout their establishment.

Mr. I. Mayor said, after hearing the remarkable statements which had been made respecting oil, he wondered why any coal was now burnt. He, however, believed it would be a very long time before oil would be brought to this country to be sold at a similar rate to coal and to compete with it to any extent for fuel. Previous to its adoption for general use, oil stations, similar to the present coaling stations, would have to be established; and at these stations there must be an infallible supply of oil, inasmuch as a steamer with boilers fitted to burn oil cannot at the same time burn coal. Before an unfailing supply of oil can be attained, the production must be enormously increased. At the present time our supply for furnaces is obtained entirely from the Caspian, and, so far, that supply is so uncertain that Russian owners of steamers are not yet fitting oil burners to the boilers of their ships. A pipe line is to be laid from Baku to Batoum, on the Black Sea; but it will be a long time before a supply can be got from that source to meet the demand for the Black Sea alone. However, when the time comes, there is no doubt oil will prove a very formidable rival to our English coal. Regarding what Mr. Andrew said about the carrying of oil in the bunkers—frequently oil is carried in

the double bottom compartment or peaks of steamers, the oil being considerably lighter than water will float on the top. The supply of oil is drawn from the surface of the upper part of the peak tank, and as the bottom is in free communication with the sea it is always kept full. Intimation of the oil being done is given to the engineer by the fact of the fire going out. One of our English admirals, Admiral Selwyn, maintains that our ironclads should all be fitted for carrying oil. But there is a serious difficulty in the way. If a shot or shell penetrate a ship the coal is thrown in every direction, but if petroleum (instead of coal) were injected into the ship in the vicinity of lights the danger would be greatly increased. Again, many of our existing ironclads depend for protection upon their carrying of coal, and this protection would have to be replaced by some other means. In reply to Mr. Arnison, the ships that have been altered have obtained five years' charters, and it is hoped that in that time they will make a considerable sum of money. By taking out the middle line bulkhead these vessels can then be made to carry grain or any ordinary cargo, and there is no material alteration in the construction of these ships and fittings to prevent them from taking any kind of cargo satisfactorily.

Mr. R. S. WHITE said, there were one or two points upon which there seemed to be a good deal of misapprehension, and one was with reference to the effect of petroleum on iron. His own opinion, from experiments made, was that petroleum was a preservative to the iron in a very marked degree, and, therefore, he thought there need be very little apprehension on this point to cause shipowners to hesitate to build special ships from fear of deterioration in the ship from the effects of carrying petroleum. In reference to the question of petroleum vessels carrying a return cargo of ordinary description, it was claimed for the designs (Fig. 12 and 12A, Plate V.), with conical bottom, that they were specially adaptable for this purpose, as the form of the bottom, with its plain surface, rendered unnecessary the use of wood ceiling, and, therefore, got rid at once of all smell from the petroleum. It was stated that although astaki might be carried, it would not do to carry refined petroleum on a ship without the use of cement, he thought the less they had of anything else but iron to iron the better. If the structure was so arranged at the start as to reduce the number of unnecessary thicknesses, and the best material was put into that structure, and see that only the very best workmanship was allowed, then there need be no fear as to any evil effect resulting from the carriage of petroleum in bulk. So far as the experience of the firm he was connected with went, the results of their testing in the "Glückauf"

were certainly very successful, and which tests were made under the supervision of Mr. Gravell, who had the personal inspection of the ship. He further ventured to assert that such a series of tests had never yet been applied to a merchant steamer or war vessel as the "Vorwärts," the ship they had launched yesterday, had successfully passed through—absolutely without a rivet having been taken out, and in the whole of her many compartments there was not a single leaky connection.

Mr. J. TWEEDY said, the working of the steamers his firm had built for burning oil did not quite bear out the theories and anticipations of Mr. Nichol. He was not in a position to say definitely what the results had been, as the papers and documents from the place where the steamers were working had not yet come to hand. Referring to the remarks of a previous speaker, he might say that they had found no difficulty whatever in filling the ballast tank, made specially for carrying oil, and placed below the engine and boiler room. They had adopted the ballast tanks with great success, and the oil was filled from the ship's deck through a very deep tube.

Mr. J. A. ROWE said, in listening to the paper, he was struck with one fact that had not been commented on. It was well known that when petroleum was burnt, little, if any, soot was disengaged and left in the tubes. It therefore followed that tubes of a much smaller diameter than those ordinarily employed might be used in petroleum burning boilers; and, if the same total tube area were maintained, it would be easy to increase the heating surface by about 50 per cent. Perhaps an objection to the use of smaller tubes would be the greater difficulty of removing the lime deposit from them on the water side. To obviate this, he recommended the use of fresh water. By these means, a suitable boiler could be obtained, and worked on lines most likely to produce success in petroleum burning. Obviously, to compare the efficiency of petroleum as a combustible with coal, a boiler embodying all known improvements ought to be built for the former. In reply to Mr. Arnison, he observed that as petroleum was composed of carbon and hydrogen, and neither of these was deleterious, there was little danger of a vessel's hull being injured by contact with the oil. With regard to the transport of petroleum in bulk, this was now an accomplished fact, but the dangers which might arise from petroleum vapours were, in his opinion, neither vague nor imaginary. But such dangers as existed, would be considerably reduced by the use of electric lights in lieu of common oil lamps or candles.

The PRESIDENT said he thought the paper and discussion together

had brought the matter very fully before them, and the two main points, viz., the method of consumption, and the method of carrying the oil, seemed to have been pretty satisfactorily settled; and now it remained simply a commercial question, viz., whether they could get the oil at a price that would pay to burn it. If the oil was to cost more than 20s. per ton, and they could get coal at 10s., it would not pay. From all they heard the supply seemed to be almost unlimited, but it would, of course, take time to develop and carry out the arrangements for placing it in the different parts of the world, where it might be required. He did not think that coal was going to be superseded by oil altogether, but it was making rapid progress, and must ultimately—to a large extent—take the place of coal.

Mr. NICHOL said, so many of the speakers during the discussion had effectively answered each other that, as far as liquid fuel was concerned, the points requiring further explanation might be summarized under three heads :—The sources, available quantity, and probable permanency of petroleum supplies; the probable cost; and the efficiency of liquid fuel. The source from which petroleum is derived appears to be the Crystalline or Metamorphic series of rocks, lying far below and much older than the coal-bearing strata. These rocks, or, at least, parts of them, have, at a remote period, formed the soil in which subtropical vegetation flourished, and by the action of pressure and subjacent heat have been changed or metamorphosed into blue clay, clay slate, shale, mica-schist, and gneiss. The wells of the American continent almost without exception penetrate into strata much older than the Carboniferous, and the apparently exhaustless supplies of oil well up, or are pumped up, from the Metamorphic series at depths of occasionally 2,800 feet. The maximum depth bored, up to the present, on the Apsheron Peninsula, is only about 800 feet; but that the oil supplies emanate from the Metamorphic rocks is shown by the vast quantities of blue clay ejected by the mud volcanoes, some no larger than molehills, others hundreds of feet high, which exist wherever the oil-bearing strata crop to the surface. The petroleum industry being in a state of transition it is not possible to predict the quantity which may become available in the immediate future. It may, however, be stated that for the last few years the average annual delivery by the 9,000 miles of pipe lines in operation in Pennsylvania has been 4,000,000 tons; and at Baku, 1,700,000 tons during the last year. Messrs. Nobel have fourteen spouting wells plugged up, which, if in full work, would supply many times the quantity at present obtained, and were cheap and ample means of transport provided to enable the produce

of these wells to be sent to the European and Asiatic markets, they would doubtless be put in full operation. The Tertiary strata, overlying the Metamorphic system, on the Apsheron Peninsula, appear to be thoroughly saturated with oil, similar to a sponge dipped in water, and, indeed, throughout the whole Caspian region petroleum exists in great abundance. Of the 1,200 square miles composing the Apsheron Peninsula only four square miles have been exploited. On the Sea of Azof the Standard Company Russe have a concession of 2,000,000 acres of land, extending 200 miles up the Kuban Valley, rich in the finest qualities of petroleum, and of this vast area only a few acres in the neighbourhood of Ilsky have been exploited, the produce being conveyed by pipe lines to Novorissisk. If these oil fields alone were as well worked and provided with pipe lines as the Pennsylvanian district in America, sufficient oil would be obtained to supply the demands of Europe and leave sufficient surplus to abundantly supply petroleum stations throughout both Europe and Asia wherever coaling stations exist at present. The permanence of the petroleum supply appears to be well assured. There is no evidence of decline in the American supplies, and the enduring character of the supply in Southern Russia is thoroughly established, particularly on the Apsheron Peninsula. Generally, wherever the oil-bearing strata lie near the surface, large beds of "kir," a peculiar kind of asphalte, are found, sometimes as much as 10 feet in thickness, while beds of double this depth have been passed through in boring. This "kir" is the residuum after the evaporation, or sun-distillation, of the lighter and more volatile portions of the oil. The number and thickness of these beds show conclusively that immense volumes of oil must have welled up from the earth throughout vast periods of time previous to the 2,500 years during which the "fire-breathing peninsula" has figured in history. In parts of our own country the existence of petroleum has been known for many years. It has been found in Lancashire, Shropshire, and Derbyshire, and from these sources Young, in 1847, obtained his illuminating oils, and continued to do so until it was found that boghead coal was richer in paraffin. The gas springs in the neighbourhood of Edinburgh and Glasgow are ample evidence that there petroleum exists in greater or less abundance. In addition, we have large tracts of oil-bearing shale, from which liquid fuel may be profitably distilled; and, if the coke annually produced in England were made in any one of the various systems of coke ovens in operation, by which bye-products are recovered, it would probably be unnecessary to use a single gallon of foreign oil, or, indeed, of British coal, as fuel for the whole of our mercantile fleet. Gas tar, which is

rapidly being supplanted by petroleum for various industrial purposes, may be well and economically used as fuel. It is said that the quantity produced in London alone is about 115,000,000 gallons per annum. The future price of petroleum is a very uncertain quantity, but it is not difficult to show that, even at the prices given by Captain McNab, whose contribution to the discussion can hardly be over-rated, petroleum refuse may be economically used as liquid fuel, if crude instead of refined petroleum be imported. The price, at Batoum, he gave as 20s. per ton, and as the cost at the wells, since 1880, has been two copecks per pood, or about 2s. 6d. per ton, the cost of transport from Baku to Batoum must be 17s. 6d. The freight from Batoum to the United Kingdom is 20s. per ton in bulk, thus making the cost delivered here 40s. Russian oil yields 50 per cent. of valuable commercial products, of little value as fuel, and 50 per cent. of residuum which is useful as fuel, and as fuel only. The present prices for large quantities in London are, benzoline, 9d.; gasoline, 1s. 5d.; kerosine, 5⅝d. per gallon; but in order to make ample allowance for poor quality, or depreciation in value, the gasoline may be grouped with benzoline at, say, 8d. per gallon; kerosine, or illuminating oil, at 5d.; and anthracine, or lubricating oil, at 6d. per gallon. The low price of the latter is due to the fact that it must be mixed with a comparatively costly vegetable lubricant to render it suitable as a machinery oil. One ton of Baku crude oil contains 250 gallons, and yields—

				£	s.	d.
4 per cent.	benzoline and gasoline	= 10 gallons at 8d.	=	0	6	8
27 „ „	kerosine	= 67½ „ 5d.	=	1	1	1½
19 „ „	lubricating oil	= 47½ „ 6d.	=	1	3	9
				£2	18	6½

There is thus 50 per cent. or half a ton of valuable fuel equal in actual evaporative power to one ton of coal remaining, and the value reckoned at the cost of a ton of coal added to the value of the distilled products, will leave what may be considered a fair profit to the refiner. Mr. Arnison was of opinion that the evaporative power was not overstated, and instanced a case where 41 pounds of water were said to have been evaporated per pound of liquid fuel. There must have been a mistake of at least 20 pounds made in writing down the result, as in order to obtain such a result the constituents of the fuel must have been: carbon, 49; and hydrogen, 51 per cent.; or about 3½ times the amount of hydrogen present in any sample of petroleum or petroleum refuse yet analysed; and the

hydrogen (if any) liberated from the steam in the furnace would not account for the difference. On the other hand, Mr. Tweedy thought the results given were high, and did not accord with his experience; these figures, however, may be readily verified by comparison with the results obtained by other experimenters. Mr. Urquhart gives the results obtained with 143 locomotives, on the Grazi Tsaritsin Railway (*Engineering*, June 25th, 1886), for a whole year's running, at 51 tons of petroleum refuse, against 100 tons of anthracite coal, which practically agrees with the results secured by Colonel Sadler. Mr. Mavor was of opinion that it will be long before liquid fuel is likely to be used in ships of war. It is quite possible that his opinion may prove to be correct; but the British Government is showing some inclination to follow the example of that of Russia, for Mr. Percy Tarbutt stated, in a paper read by him a week ago, before the Society of Engineers in London, that our Government has decided to place a torpedo boat at his disposal for experimental purposes. The fact that coal in bunkers forms a good protection for the machinery is not at all likely to prevent the introduction of liquid fuel into the navy, seeing that the machinery is generally below water-line, and that even more effective systems of protection than coal affords may be adopted. Petroleum refuse, or astaki, having been freed from volatile constituents, and its flashing point being so high as 320 degs., and burning point 420 degs. Fah., no danger attending its use as fuel need be apprehended.

Mr. GRAVELL said, a great deal of prejudice seemed to exist as to the fear of explosion, which, he thought, might really be banished; indeed, there was no more danger of explosions in such vessels than in a vessel carrying a cargo of coals; because in these vessels which carried petroleum, every precaution was taken, viz., the engines were isolated from the cargo, no naked light was allowed, and the electric light was fitted throughout, whereas with a cargo of coals none of these precautions were used. To his mind, it was almost impossible for explosions to take place with the present system of carrying oil in bulk, if ordinary care and precautions were taken. In regard to the remark from Mr. McNabb respecting the classing of this type of vessels by his society, viz., the Bureau Veritas: their committee, after due consideration and some previous experience, found that this type of vessel was about the safest kind that could possibly be put afloat; besides, the oil compartments had been put to the severest tests, viz., a column of water 15 feet above the deck, without showing the least sign of leakage. He also thought it was unwise to hamper the shipowner and shipbuilder

with the extra material and cost for the double skin, and further reduce the carrying capacity of these ships, as experience had already shown that such construction did not contribute to the safety of the vessel.

On the motion of the PRESIDENT, a vote of thanks to Messrs. Nichol and Gravell for their interesting paper was carried by acclamation.

EXTRACT FROM "NEW YORK HERALD" ALLUDED TO IN MR. ANDREW'S REMARKS.

MR. DICKEY'S process is so simple that a tyro in engineering can understand it at a glance; and yet, on the trial trip it fully verified its pretensions to be considered a practicable method of substituting petroleum in the crude state for coal in moving railway trains. The crude oil is contained in a large iron tank upon the platform of the tender. The tank is constructed of iron plates firmly riveted together, pains being taken to render the receptacle of the fuel practically impervious to air. Two pipes lead from the tank to the furnace, each delivering at the furnace a jet of crude petroleum under very light pressure. If in this condition the highly-inflammable oil were to be ignited, it would burn with a brilliant flame, but the combustion would be imperfect, and the amount of heat generated would be small in comparison with the actual capacity of the liquid fuel. Hence, the conversion into gas has been regarded as a condition precedent to success by most inventors. Mr. Dickey overcomes the difficulty in a manner that is at once simple and efficient. Placed at right angles to the nozzle that delivers the petroleum within the furnace, is a second nozzle, which delivers under high pressure a jet of superheated steam. The two jets thus meet each other at right angles, and the current of oil is instantaneously reduced to a finely divided vapor by the combined heat and force of the steam. This vaporizing process is different from the conversion into gas, and fills the furnace with a petroleum spray mixed with heated vapor of water. The third requirement is to mingle a sufficient volume of free air (or oxygen), at a high temperature, with the compound vapor produced by the petroleum and steam, to render the combustion perfect when the contents of the furnace are ignited. This is accomplished by a peculiar construction of the steam nozzle, which not only propels a jet of steam against the thin stream of oil, but draws after it a current of heated air, which also mixes with the vapor. All the elements of combustion are now present—the carbon in the finely divided vapor of the oil, the oxygen that forms one element of water, and free oxygen in addition, and the furnace is filled with a seething, hissing, pungent vapor, which blazes instantaneously upon the application of a lighted vesuvian. What takes place on ignition can readily be inferred. The atoms of highly heated carbon unite rapidly with the heated oxygen, and a temperature capable of decomposing the steam into hydrogen and oxygen is instantaneously produced. This adds to the supply of the latter element, while the hydrogen, with its pale blue flame, reunites in some measure in burning with its former element. It is not claimed that there is any gain in the amount of heat generated from the decomposition of the water and the combustion of its hydrogen; but the jet of steam is necessary to

the vaporizing of the oil, and the disposition thus made of it compensates for the expenditure of heat required to produce it—that is, to heat the water to the high temperature at which it is delivered. The preceding simple details constitute all the essential features of Mr. Dickey's invention for burning liquid hydro-carbons without first converting them into gas. The perfection of the combustion may be inferred from the fact that while a sheet of paper placed over the smoke-stack of a furnace soon becomes damp with the moisture produced by burning hydrogen, no minute brown or dark spots, such as would be produced by particles of incandescent carbon appear upon its surface. There is, consequently, no measurable loss of carbon from this source, which, in the combustion of coal, is one of the principal causes of waste.

The distance traversed yesterday by a train of two cars fairly loaded with passengers on the trial trip was 33 miles—to Rockaway and return. The distance thither, 16·5 miles, was accomplished in 45 minutes, that being the regular schedule time on the Long Island Railroad; but the Rogers has been run 40 miles an hour with crude petroleum during the progress of the present experiments. The quantity of oil required to get up steam and make the trip was estimated at 70 gallons, and the cost of the fuel for the trip was $1 20, against an expense of about $2 for coal at present prices. The movement of the train was easy and uniform, the pressure of steam remaining steadily at about 100 pounds. The space occupied by the fuel was less than one-fourth what would have been required for the coal to run the same distance, one pound of petroleum doing the work of four pounds of coal on the average—a point of great importance to marine engineers. When the train arrived in the depôt at Long Island City the oil and steam were turned off by simply turning the stop-cocks that regulate their delivery, and instantaneously the glowing heat of the furnace ceased, its blaze went out, and the work was ended. It is stated by engineers that a boiler will last fully twice as long with petroleum for fuel as it will with coal; no cleaning of the furnace or handling of the fuel (after it has once been put in the tank) is required; so that on steamships it would be possible to dispense with the services of the army of firemen and coal-heavers now employed, and to fill their places with two or three junior engineers.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886–87.

PROCEEDINGS.

THIRD GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE SUBSCRIPTION LIBRARY, FAWCETT STREET, SUNDERLAND, ON WEDNESDAY EVENING, 8TH DECEMBER, 1886.

W. THEO. DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the last general meeting, held in Newcastle-upon-Tyne on November 10th, which were approved by the members present, and signed by the President.

The ballot for new members having been taken, the President appointed Messrs. W. S. Norman and R. Readhead to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Allan, James McNeal, 5, Edith Street, Jarrow-on-Tyne.
Baxter, William J., 6, St. Mary's Place, Glasgow.
Blumer, William, Rockside, Roker, Sunderland.
Carter, George J., Elswick Shipyard, Newcastle.
Dalrymple, William, Messrs. Hawks, Crawshay, & Sons, Gateshead.
Dugdale, William H., Messrs. Boolds, Sharer, & Co., Sunderland.
Fairweather, C. W., Messrs. Ernest Scott & Co., Close, Newcastle.
Fletcher, Robert, Walker Forge, Low Walker.
Macdonald, James, jun., 7, Claremont Street, Glasgow.
Purvis, John, 1, Broughton Road, South Shields.
Robson, Arthur, Messrs. John Blumer & Co., Sunderland.
Roylance, E. H., Messrs. Ernest Scott & Co., Close, Newcastle.
Thompson, James, 11, Elmwood Street, Sunderland.

GRADUATES DESIRING TO BECOME MEMBERS.

Barley, Clement J., 26, North View, Heaton, Newcastle.
Fisher, John, 46, Croft Terrace, Jarrow.
Grieves, Robert, 38, Linskill Terrace, North Shields.

ASSOCIATES.

Allden, William R., Akenside Villa, Newcastle.
Briggs, Robert S., Moorlands, Sunderland.
Browne, John L., Thornhill Gardens, Sunderland.
Craven, John, The Cloisters, Sunderland.
Gardner, Colin, 13, Rosslyn Street, Sunderland.
Greenwell, Thomas G., Sunderland.
Hedley, John H., 10, Esplanade West, Sunderland.
Hudson, Ralph M., jun., 8, The Cedars, Sunderland.
Pinkney, David Gallon, Sunderland.
Pinkney, Thomas, Cresswell Villa, Sunderland.
Sanderson, John, 9, The Elms, Sunderland.
Speeding, James, Roker House, Sunderland.
Thomson, V. T., Baltic Chambers, Sunderland.
Taylor, John W., Thornhill Tower, Sunderland.

GRADUATES.

Chisholm, Alexander, 64, Clayton Street, Jarrow-on-Tyne.
D'Eyncourt, Eustace, 2, Hawthorn Terrace, Newcastle.
Nicholson, John, Messrs. Black, Hawthorn, & Co., Gateshead.
Ross, Archibald T. C., 19, East Parade, Newcastle.
Speeding, Joseph C., Roker House, Sunderland.
Skinner, Leslie, 22, Ravensbourne Terrace, South Shields.

The following paper "On the Plan and Construction of Marine Engine Works," by Mr. Thomas Mudd, was then read:—

(Photographic views of the interior of the various workshops were shown upon the screen by means of the lime light.)

PLAN AND CONSTRUCTION OF MARINE ENGINE WORKS.

By Mr. T. MUDD.

During the years 1883 and 1884, the writer was engaged in planning and building the new marine engine works at West Hartlepool, belonging to the Central Marine Engineering Company, and he thought it might perhaps be of interest to the Institution if he gave a brief sketch of these works, and their equipment. In doing so, prominence will be given to such features as are of importance in all marine engine works, rather than to such as have been rendered expedient in these particular works owing to local circumstances.

A modern marine engine works is a very wide field to be embraced within the narrow limits of a single paper, and it is clear that this account can only claim to be a very general survey of the subject. The writer will classify his remarks under the following three headings :—

I.—Environment.
II.—Ground plan, and general arrangements.
III.—Building construction.

I.—Environment.

A marine engine works is, perhaps, more urgently in need of satisfactory surroundings than any other kind of works that can be named; and its means of communication with the outer world are of the very first importance. It is desirable—

1.—That there should be road, rail, and water communication for the inlet and outlet of goods.
2.—That a quay, where vessels may be engined, should be close at hand, and, if possible, a dry dock also, in view of repair work.
3.—That there should be satisfactory deep water communication to the engine works from the shipyards supplying the vessels to be engined.

The site of the engine works under description possesses all these advantages. Road and rail traffic can approach the works freely. Vessels with pig iron from the Tees or Grangemouth can discharge direct on to the

foundry bogies. The works stand along the face of a quay, 700 feet in length, on which there is a set of 80 ton hydraulic sheers, 110 feet in height. A dry dock, 600 feet long, lies close alongside the works on the west, and unequipped vessels from any of the four shipyards at the port can go to the engine works without having to go out of the dock system into the open sea.

The facilities for passing finished work from the works to the sheers, and for there shipping it are such, that a set of triple engines, of 1,000 horse-power, with boilers, shafting, and propeller complete, can be fitted on board the vessel and steamed back to the shipyard on the fifth day after the ship's arrival at the sheers.

II.—Ground Plan and General Arrangements.

The site is a triangular one, having a frontage of 830 feet along the quay, and contains nearly eight acres.

In parcelling out the ground to the various large departments, it is desirable—

1.—That the iron foundries should be near the engine shops.

2.—That the engine shops and boiler shops should be within easy communication with the sheers.

3.—That the repairing and sheer-legs shop, copper shop, and joiners' shop should be conveniently situated in relation to the sheers and dry docks, if any.

4.—That the pattern shop should be detached from all others, but have rail communication with the foundry.

5.—That the forge should be a satisfactory distance from the engine shops to avoid vibration in the latter from the steam hammers.

6.—That the smiths' shop should adjoin the forge so as to be under one foreman, and should have rail communication with the engine shops.

7.—That the store house, brass foundry, brass finishers' shop, tool fettlers, grinders, etc., should be conveniently situated in relation to the engine shops.

8.—That such departments or apparatus, as have to deal with almost every other department, should occupy as central a position in relation to the whole works as possible, as, for instance, the commercial offices, the drawing office, the steam boilers, the hydraulic engines and accumulator, the electric engines and dynamos. The only exception to this rule is the gas plant, which should be well removed from the general works.

These points were all carefully watched, as will be seen by reference to the general ground plan (Plate 12); and, at the same time, the fact was not lost sight of that, in view of the advantage to the stability of the structure, the ground plan should be such as to permit the loftiest shops being in the middle, the lower and still lower ones being ranged outside them to support them, and avoid, as far as possible, presenting any very large flat surface to the action of the wind.

Coming now to consider more in detail the plan of the various departments, and, commencing with the iron foundry, it is not too much to say that there is no department of an engine works that will better repay a studied care in the arrangement of its various parts and details than the foundry department.

The features affecting the ground plan of that department that seemed most important were the following :—

1.—The loam and dry sand work should have space allotted to it apart from the green sand work.

2.—These sub-departments should be so situated as to be easily overlooked by one foreman.

3.—All cupolas, with their blowing apparatus, should be situated close together in one group.

4.—They should be placed so as not to encroach at all on the clear floor area between wall and wall, and should yet be so enclosed as to enable their management to be overlooked by the foreman from the inside of the shop.

5.—It should be possible to draw metal from the cupolas directly into either the loam foundry or sand foundry.

6.—The correlation of the two foundries and the cupolas should be such that every ladle of metal that is heavy enough to need the assistance of a crane, may be received by the crane directly from the cupola, and thus not involve the troublesome and somewhat dangerous expedient of conveying the ladle across the shop on a bogie.

7.—In the sand department a great quantity of molten metal has to be carried in small hand or bogie ladles, and, therefore, it is most desirable that in this shop the cupolas should be situated near the middle of the length of the shop to minimise the distance of hand carrying.

8.—There should be ample yard accommodation in close proximity to the cupolas, and accessible from both loam and sand shops.

9.—In the sand foundry there should be one or two good stoves for such cores as are required in connection with the sand moulds.

10.—The loam foundry should be sufficiently wide to accommodate a range of capacious casting pits, and a broad core floor alongside of them.

11.—There should be ample stove accommodation in connection with the loam department, if possible, co-extensive with the core floor and casting pits, and so situated in relation to these as to involve the minimum of labour in passing cores from one to the other.

12.—These stoves should all be accessible from the *back*, whether gas or coke firing be adopted.

13.—Provision should be made for the storage of loam, and for the grinding of same. If possible, the arrangements in connection therewith should be such that the loam may be discharged directly from the trucks into the store, thrown directly from the store into the mill, and directly from the mill into hoppers on the core floor, from whence it is readily taken to the cores and moulds.

14.—Whilst the foundries should have short and easy communication with the engine shops, both by railway and hand bogie track, they should yet be completely separated therefrom, so that the machinery of the engine shops may be preserved from the bad effects of the dust that is inevitable in the foundries.

This seems rather a formidable list of requirements, but a careful inspection of the detailed ground plan of the foundries, as seen on Plate 13, will show that all have been satisfactorily met.

The ruling idea in this foundry is the placing of the loam shop and sand shop at right angles to each other, the ground enclosed in the angle forming the foundry yard, and the point of the angle being occupied by the cupolas.

This is the key to the possession of a great number of facilities which it would be practically impossible to obtain by any other arrangement.

Between the foundry and engine shops a road is carried through the works from front to back, entirely separating these departments without interfering with the easy communication between the two, and providing means for getting at the backs of all the stoves, and of bringing loam on the railway close to the store.

Overhead steam cranes and hydraulic jib cranes are fitted to both the foundries. There are two large casting pits in the loam shop, one being

70 feet long by 22 feet wide, the other 34 feet long by 19 feet wide. A 5 ton hydraulic pillar crane stands between the pits. The pits, and core floor, and stoves are arranged parallel with each other, and the overhead crane is sufficiently powerful to lift out a large casting, with core and all included, as soon as cold enough, to permit of another being commenced in its place.

Engine Shops—Ground Plan.—Turning now to the engine shops and their accessory departments, the important features seemed to be the following:—

1.—There should be a wide bay for erecting shop, and, if possible, this bay should be long enough to accommodate all the machines that have to deal with the heavy class of castings, so that these castings need never be passed from one bay to another, but remain always under the same travelling cranes. This enables the travelling cranes in the adjoining bay to be much lighter than those in the erecting shop,

2.—There should be at least one other wide bay traversed by overhead cranes, and suitable for heavy turning and machine work. This plan is much preferable to one long continuous bay.

3.—Accommodation is required for a large quantity of small and medium sized lathes and other machines, which do not need the assistance of overhead cranes, and for this purpose from two to four more bays will be required, according to width and length, and these may either be on the ground level or galleried over each other.

4.—All these bays should be clear and open to each other between the columns to facilitate overlooking by the minimum number of foremen.

5.—Material should come in at one end of the shops, and finished engines go out at the other.

Besides these the following are of interest, although not directly affecting the ground plan of the shops:—

6.—As far as possible the machines should be so situated that large pieces of work may progress systematically through the shop, from the marking off table at the inlet end to the erecting table at the outlet end.

7.—Many advantages seem to arise from the plan of driving each of the several lines of main shafting by a separate engine; and it is better still to have these engines fixed on the columns driving direct on to the shafts.

8.—At about mid height of the columns there should be a line of countershaft girders so designed that countershaft brackets may be readily fixed at any point without making holes, and these girders may act as struts to the columns, etc.

9.—All pipes that cannot be carried overhead should be in a proper trench, where they can be easily got at, and should not be buried in the ground.

The arrangement of the engine shops is shown in plan on Plate 14.

This department contains 56,500 square feet of floor area, and the ground floor is entirely paved with wooden blocks, on end grain.

Parallel with the engine shops, and adjoining same, is a bay, 53 feet span, containing some of the smaller departments, namely, the offices in front, and behind them the grinders, tool fettlers, main boilers, brass finishers, store house, and brass foundry.

A word may be said in passing regarding the plan in connection with the general store house. It is square in plan, and galleried all round. It has a door in the centre of each of its four sides. One opens on to the roadway through the works, and accommodates the inward and outward flow of goods by road and rail. The door and window opposite open into the lathe shop, and are for the delivery of goods to the workmen. A third opens into the brass foundry, and enables all raw material in connection with that department to be kept in the store house and given out as required; the brass castings being received into the store house as made. The door on the fourth side opens into the brass-finishing shop, and provides for the delivery of brass castings to that department, and the receipt of all finished brass goods from it. These arrangements greatly simplify the keeping of accounts in these costly materials.

Immediately within the doors, at the inlet end of the erecting shop, there is a 20 feet square level marking-off table, flush with the floor, on which large castings, etc., can be marked off accurately with surface gauges in a very short time.

Following down the shop are two powerful cylinder boring mills, a 10 feet chuck lathe, suitable for liners and pistons; a heavy vertical boring machine, with 8 inch spindle; a 4 feet 6 inch slotting machine, two large horizontal and vertical planing machines, a heavy 6 feet ordinary planing machine, two horizontal drilling machines, one of them capable of covering a vertical area 20 feet long by 16 feet high; and two large radial drilling machines.

These machines occupy about half the length of the shop. Beyond that is space for the testing and cleading of cylinders, etc., and a range

of heavy cast-iron erecting tables, flush with the floor, on which the engines manufactured are erected and steamed before leaving the shop. The details and advantages of these erecting tables would require a short paper to themselves to describe satisfactorily.

Boiler Shops—Ground Plan.—Passing on to the ground plan of the boiler shops, the following may be mentioned as important points to be kept in view:—

1.—As in the engine shops, it is better to have two bays of moderate length, traversed by overhead cranes, than one very long one. The wider and loftier bay of the two should have the heavier overhead travelling crane, and contain space enough for all the boiler *building*, and all the machinery that has to deal with shell plates after they are bent. The narrower bay may thus have a lighter overhead crane, and should have space enough to deal with plates in the flat and with all interior work.

2.—If these two bays are entirely absorbed by the boilers proper, considerable further space will be required for the light work, such as smoke boxes, uptakes and funnels, ladders, gratings, and platforms, and for the light machinery in connection therewith.

3.—The large plate furnace should be practically outside the shop, but its doors should open into the shop.

4.—There should be a large boarded floor for drawing-board, and this should be outside of the clear area of the shop floor.

5.—A subsidiary store house is desirable, and should be as accessible as possible from all parts of the shop.

6.—Suitable storage places for tubes, plates, and bar iron are most desirable, and should be so arranged that they receive goods at one side from the railway outside, and deliver them at the other side into the shop.

7.—Some yard accommodation is necessary about the boiler shops for the accumulation of scrap, etc.

8.—As in the engine shop, the arrangements should enable material to come in at one end and finished boilers to go out at the other, the various operations being performed on the work as it progresses systematically through the shop.

Plate 15 shows the ground plan of the boiler shops. At the north end of the principal bay there is a deep recess, 50 feet long by 25 feet wide, in which is placed the large hydraulic riveter, so that the shell

riveting is carried on outside of a line drawn along the shop side, and does not encumber the shop floor or impede the overhead traveller. There is a special overhead traveller over the riveting machine for its particular use.

At the front end of the shops a bay with lean-to on each side, making a width of 75 feet, is carried along to the westward, about 110 feet, for the light work.

A is the plate furnace, B is the drawing-board, C is the plate store, D is the tube store, E is the store house for tools and sundries, F is the bar iron store, G is the light plate store, H is the store for ropes and tackle, I is the angle iron store.

All trucks containing heavy plates come under a travelling crane at J, and are unloaded thereby. All those containing bars, tubes, or light plates go on the siding at K, and are there unloaded into their respective stores close by.

The furnace has a door at its end opening into the narrower bay, and another at its side opening into the wider bay. The hydraulic crane at the corner moves by power through three-fourths of a circle, and accommodates both doors. The large shell plates are marked off and planed in the narrower bay, and the vertical rolls are so placed as to be able to receive them in the flat from the crane in the narrower bay, and deliver them bent to the crane in the wider bay, where they then remain through all future stages.

The hydraulic flanging machine is placed at an angle so that a plate may be passed into it from the furnace in the shortest possible time.

The hydraulic riveting machine has a gap of 10 feet, and the 25 ton crane above it is entirely manipulated by the man on the machine whilst he has his eye level with the rivet.

The shell drilling and building of the boilers is all done in the wider bay.

Copper Shop—Ground Plan.—On the same plan, Plate 15, will be seen the ground plan of the copper shop, which occupies the extreme western corner of the works.

Pattern Shop, Forge, and Smiths' Shop—Ground Plan.—These are situated on the piece of ground at the back of the main works. The ground plan of the pattern shop, smiths' shop, and forge, and also the position of the gas producers, are shown on Plate 12. It will be seen that the position selected for the forge is the furthest possible away from the engine shops.

III.—Building Construction.

On this part of the subject, the writer proposes to touch very briefly, referring only to the main features of interest.

Foundations.—Having to deal with about 17 feet depth of newly made ground, it was necessary to get a footing for the principal weights below this.

The main buildings, except the pattern shop, depend upon large ⊢ section cast-iron columns, of which there are about 150, and it was found cheaper, and thought safer, to carry these columns down 12 feet 6 inches into the ground, than bring up concrete piers to the surface.

Columns.—The principal columns carry as much as 200 tons maximum load, and this is borne on concrete bases having 80 square feet area. On these are placed large cast-iron shoes, into which the columns are placed and run up with cement. The principal columns are 3 feet by 18 inches at the bottom, tapering towards the top. A large number of them are over 44 feet in length.

It will readily be conceded that one of the most important conditions to secure in connection with columns carrying heavy loads, is that these loads should be applied vertically over the base; and if it be impossible to have them quite over the centre of the base, the point of application should be within the boundary lines of the column sides. This was easy of attainment where the columns only carried one line of overhead cranes; and the method adopted for attaching the upper columns carrying the roof to the main columns, was that of splicing them to the side, as shown in Plate 16 (Fig. 1), a snug beneath the end of the upper column taking the shearing strain off the bolts, and rendering fitted bolts unnecessary. By this means a better attachment is secured than by a horizontal joint, and both the pieces are simpler forms to cast.

The general arrangements adopted, made it possible to secure similar advantages in the columns carrying cranes on both sides; for since all the heavier pieces of work were to be dealt with in the wider bays, it is clear that not only could the cranes in the adjoining bays be lighter, but they could also be lower. By dropping the seat of the longitudinal girders in the narrower bays 8 feet, which experience has shown still to leave abundance of height, the end carriage of the lower cranes could pass beneath the snugs that carry the upper columns. This is also illustrated in Plate 16 (Fig. 2), where it will be seen that the centres of application of all the weights fall within the side lines of the columns, and since the rail centres of the travellers are only 19 inches apart, the cranes can approach each other all the more nearly, and there is all the less floor

space left uncovered by crane power. This latter point is one not to be despised, when the placing of the machines is considered, as the centre line of a lathe or other machine is frequently dependent upon the extreme point that can be plumbed by the crane hook.

The total weight of columns, shoes, etc., is about 1,200 tons.

Girders.—The wrought iron longitudinal girders for carrying the overhead cranes are double webbed fish-bellied plated girders, with a safety factor of not less than four on the maximum load. There are about 400 tons of these fish-bellied girders altogether. (See Plate 16.)

Along the upper ends of the upper columns Belgian rolled I beams are fixed to form "wall plates," the principal section used being 14 inches by 7 inches. There are about 60 tons of these used.

Roof.—It was decided to have a roof of such a type as would permit of a large amount of roof light, and which should contain no woodwork whatever. The principals consist of steel rounds in tension, and iron flats, angles, and tees in compression. The covering is corrugated sheeting, and rough rolled plate glass. The shop columns are pitched 24 feet apart, and the roof principals 8 feet apart. The roofs contain about 600 tons of iron and steel. (See Plate 17.)

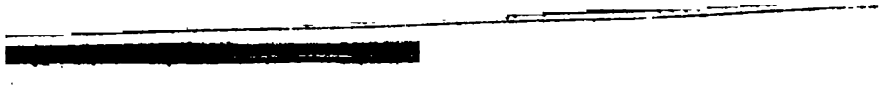
The pattern shop is a three-storey building, the walls of which are of brick. It is 150 feet long by 40 feet wide. The ground floor is paved with wooden blocks, and has a railway with bogie carrier running the whole length, and is used for storage of heavy patterns.

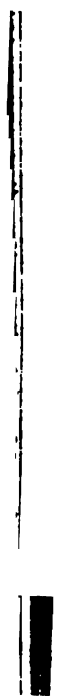
The floors of the two upper storeys are carried by timber beams, heavily trussed by wrought iron tie rods. The middle floor carries the various machine tools used in pattern making, this storey being used as the working shop.

The upper storey is fitted throughout its whole area with racks for the orderly and systematic storage of small patterns, every space being numbered, and a register kept in the room of the number of the space in which each pattern may be found. To get as much rack space as possible, there are no windows in the side walls of this upper storey, the light being entirely roof light. The roof is of the composite type, the struts being of wood, and the ties of iron, the covering being slates.

Lighting.—The engine and boiler departments of these works are lighted by fifty 2,000 candle power arc lamps, driven by two separate engines and dynamos on two independent circuits. The local lighting is done by gas.

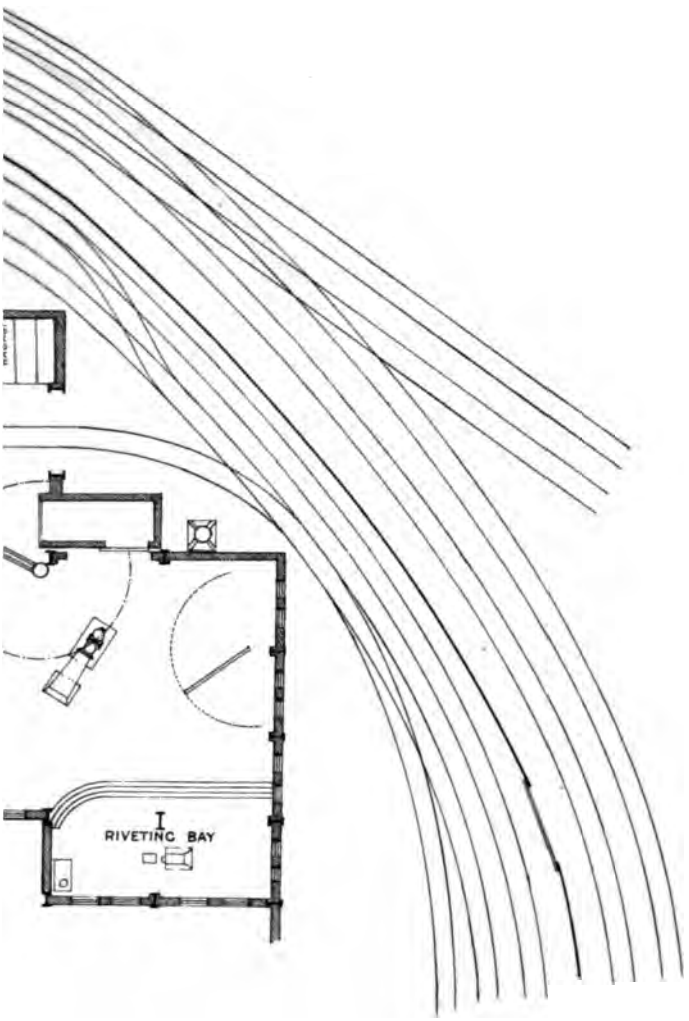
Firing.—Almost the whole of the heating is intended, ultimately, to





nstruction of Marine Engine Works."

Scale 1/20' - 1 Foot.



And Rev. Lith. Newcastle

be done by gas, from a number of gas producers, which are already erected, but which it is not intended to put in operation until cleaning plant has been attached.

Hydraulics.—A powerful set of hydraulic pumping engines are daily at work on an accumulator, working at 1,000 lbs. pressure per square inch. Hydraulic power is carried into each of the large departments, and is utilised not only in cranes and tools, but in lifts to the galleries, and in hoisting up and down the great doors at the inlet and outlet ends of the shops, and considerable additions to the applications of hydraulic power already made are contemplated.

In thanking you for listening to what is necessarily—on account of the very wide character of the subject—a mere outline sketch, the writer trusts that his imperfect remarks may call forth an instructive discussion.

Mr. B. G. NICHOL said, the principle laid down by Mr. Mudd, in commencing to lay out a large engineering works, was thoroughly sound and in accordance with economic principles, viz.:—that the raw material should enter at one end of the works, and passing forward by progressive stages, should leave as finished product at the other end. This principle had been adhered to and ably carried out by Mr. Mudd as far as the form of the piece of land at his disposal would allow, and the way in which the details had been worked out and adapted to the purposes required is worthy of all admiration. The general plan could not, however, be regarded as an ideal arrangement. He thought the most perfect form for an engineering works was a square or rectangular area having one side parallel with dock or river, and a railway parallel with the other side, with suitable sidings running into the works; this area, he thought, should be divided into two parts by a wide roadway running from the railway at one side to the dock or river at the other, where the sheer legs should be situated, the various shops should be parallel with the river, and so arranged that the material should be received at the end nearest the railway and pass through its various stages of progress, leaving as finished machinery at the sheer legs.* The broad centre roadway should have a railway running its entire length

* Mr. Nichol illustrated the above by a chalk sketch upon the black board.

connected with the parallel railway before mentioned, and turn-tables arranged between each pair of shops on right and left hand, also an overhead travelling crane spanning the entire width, and running from the railway to the river, so that the spaces outside the railway might be used for yard space. He was very pleased to see the manner in which Mr. Mudd had dealt with the boiler yard; but in his experience he had found two sets of travelling cranes in the shop in which the boilers are erected, one set at a higher level than the other, of great advantage in expediting work. The ideal boiler yard is simply an epitome of the entire works, and consists of two shops, the plate rack, running alongside the first, in which all the preparatory stages of the work is performed, and in the other, the erecting, completing, and testing, the latter having a railway on which to run the bogies carrying the finished boilers to the sheers. Taking into account the formation of the ground at Mr. Mudd's disposal, it would be generally conceded that he had produced a splendidly arranged works for the construction of marine engines and boilers.

Mr. R. L. WEIGHTON said, he could not say that he was prepared to go into a criticism of the general plan of the works as Mr. Nichol had done, although it had struck him that the works did not seem to be so regular in general disposition as they might have been, but, he supposed, that as the piece of ground was the starting point, it had to be made the most of; and Mr. Mudd did not have *carte blanche* for his whole scheme, but was limited to a certain extent by the conditions of site, though this was not alluded to in the paper. Being of an essentially descriptive character, the paper to which they had just listened did not afford much scope for criticism or comment. Moreover, where it is not truly descriptive, it proceeds upon the principle of laying down general rules which, in the author's opinion, ought to guide the design of all such engine works. And here, again, there was very little latitude for discussion, because, it seemed to him, those general rules could not be objected to. He should like Mr. Mudd to amplify his paper in some parts, and, with this object in view, he would ask him a few questions. He mentions in his paper that engines are steamed before leaving the shop. Does that apply to the largest sizes, at what speed are they run, and where does he get the steam? There was another point which struck him, viz., the fish-bellied girders. Why were girders of this kind adopted? They could scarcely fail to be more expensive than if made rectangular. He did not think it occurred in the paper, and it would be interesting to know the clear height from the floor of the erecting shop to the crane hook. It was also mentioned in the paper that the ground was forced,

and that it was thought better to carry the main pillars down 12 feet 6 inches, instead of bringing up concrete piers to the surface. That struck him as being rather contrary to the usual opinions of engineers and architects in this matter; and it would be instructive to hear Mr. Mudd further on this. Also, on page 64 of the paper, it is mentioned that the girders have a safety factor of not less than four on the "maximum load." Now, as this is a point which is very important, perhaps Mr. Mudd will state what was the maximum load for which he considered it necessary to allow in the erecting shop? He very much admired the details of the works. They seemed to be replete with every modern appliance, and he was particularly struck with the arrangement on the main pillars for supporting the cranes, by which the weight falls within the base.

Mr. J. P. HALL said, he thought the paper just read and the plans shown by Mr. Mudd would be of great service to the Institution and its members generally, and he hoped the Council would be able to show as many of the plans as they possibly could in the Transactions, especially the ground plans. It would be a great guide to others having engine works to design. In reference to the plan of the general arrangements of the place, he thought it was well laid out. He thought, also, that there were evidences of great wealth about the whole establishment, at the same time there was evidence of very great care in the thinking out and arrangement of every detail to save labour in the transportation of material. The saving of labour was a very important feature when it was considered that in our engine producing works there was something like 25 per cent. of unskilled labour of the total men and lads employed, and any means that would reduce this would doubtless make a big difference in the pay bill during the year. He thought that that part of the business had been well considered and well planned, and he hoped in a very short time Mr. Mudd would have an opportunity of testing his plant to its full power and capacity.

Mr. W. DALRYMPLE said, the paper read by Mr. Mudd was a most interesting one. Evidently great care and practical knowledge had been exercised by the designer to produce an arrangement of workshops which, in his opinion, would work more economically and better than an alternative plan, suggested by a previous speaker Mr. Nichol, in which turntables were used to move the work from the shops to a main line leading to the quay. With reference to the erecting shop, the question arose—Will it pay to go in for such elaborately finished erecting tables on which to erect the engines and test by steam?

Mr. Wm. Johnstone, Lloyd's Surveyor, Sunderland, said he should like to ask Mr. Mudd a question in relation to the time it took to fit engines and boilers on board steamers after they were launched. That gentleman, in his paper, mentioned five days. Now, he should like to know if these were five days of nine hours each, or five days in which the work was carried on day and night? His experience, in relation to a considerable number of vessels, was that a longer time than five days was spent at the engine works. With regard to the paper, he could only reiterate what the former speakers had said—it was very interesting and instructive, and the arrangements showed great forethought on the part of the designer. As to Mr. Nichol's model engine works, it will be seen that all the shops adjoin each other; but he thought Mr. Mudd, in his paper, proved that that was not desirable, as the forge and pattern shops should be kept some little distance from the others—the forge to prevent vibration, and the pattern shop to reduce the chances of fire spreading to and destroying the contents of the pattern shop. From the description they had had to-night, he was of opinion that the Central Marine Engine Company had a very convenient piece of ground, and that they had laid it out to the best advantage.

Mr. R. Readhead begged to thank Mr. Mudd for his paper, which was not one for much discussion. From his experience he was able to compliment the author on the design he had adopted and carried out successfully. In criticising Mr. Nichol's sketch of his ideas of laying out similar works, he thought he altogether overlooked one important matter—the crane power, requiring to be equal in most of the spans, and the turn-tables necessary to carry the ponderous weights would be so unwieldy as to be practically useless. He must say Mr. Mudd had certainly made the most of the site he had at his disposal, more especially as to economising labour.

Mr. J. L. Thompson said, he had had the pleasure of seeing the works which Mr. Mudd had described, and so far as his idea goes they seem to be very complete, both in the arrangement all through and in the labour saving appliances. It was rather a delicate matter to discuss a particular works of this kind. It struck him the question as it was aptly named by Mr. Hall is, what is the sum you have given to start with in designing works of this kind, and if costly, whether your proportional charges are not too heavy a drag on the business? So far as what Mr. Johnstone had said of the boats steaming away so soon after being placed in the hands of engineers, he thought, when they were putting up so complete a works, if instead of the sheer legs they had had a steam crane,

while they now did the work in five days steaming (ten days to leave the port), he believed they could have done it in much less time, because in the sheer legs everything must go straight to and from the sheers, consequently there was a very considerable amount of labourage. He thought Mr. Mudd had quite carried out Mr. Boyd's suggestions with regard to descriptive papers and at the same time had opened up a very wide field.

Mr. M. SANDISON said, with reference to the sheers, he was of opinion it was an open question whether hydraulic power was preferable to an independent engine and boiler for working such an important piece of mechanism, especially if the hydraulic power was distributed over a wide area. With a pressure of 1,000 lbs. per square inch the giving out of a joint at some remote part of the factory or the failure of one of the machines might bring the sheers to a standstill—no light matter if a 40 ton boiler was hanging just over the bulwarks of a vessel in a rising tide. He had listened with pleasure to Mr. Mudd's paper.

The PRESIDENT said, not being an engineer nor having seen the engine works alluded to, he was unfortunately unable to criticise the paper. The whole scheme and arrangement had, evidently, been well thought out from the ground plan to the construction of the buildings and the placing of the machinery; and, so far as he was able to judge, Mr. Mudd had certainly got the management of one of the most complete engine works in the kingdom.

Mr. MUDD, in reply, said, referring to Mr. Nichol's remarks, there could be no doubt that the form of the complete works would have been more rectangular if he had had unlimited ground at his disposal. The shape and size of the ground, however, was the given condition at starting; and, fortunately, the area was not so small as to interfere very much with the general facilities required, or with the adoption of a rectangular form in the individual departments. It must not be overlooked that Mr. Nichol had sketched a works consisting of only two departments—an engine shop and a boiler shop. At the same time he was glad Mr. Nichol had made the sketch, because it enabled him to bring out more prominently than he had done in the paper one or two important points. For every bay on Mr. Nichol's plan there would be a turn-table in the through road from front to back. Turn-tables were abominations that he had set his face against from the first, and he was glad that he had been able to make satisfactory arrangements for getting the material into and out of these works without the use of a single large turn-table. He might say, in passing, that

another speaker had remarked on the expensiveness of the erecting tables adopted in the erecting shop. The turn-tables sketched by Mr. Nichol would have cost far more without any corresponding return in usefulness. The next point was one Mr. Readhead had already touched upon, namely, that in placing the several bays of the engine shop parallel with the quay instead of at right angles thereto, the overhead cranes would require to be of heavy calibre over every bay, as the large pieces would have to be lifted in every bay in passing crosswise through the shops, thus losing the advantage he had claimed as attaching to the plan of dealing entirely with the heavy pieces in one bay only, so that they might be always within the power of the same overhead cranes from entering at one end of the bay to going out finished at the other end. The crane power, however, was not all; there was the extreme awkwardness of passing heavy pieces through between the columns from one crane to another, the loss of labour in double slinging, and the loss of floor space in keeping several bays open to effect the passage. He thought the boiler shop sketched by Mr. Nichol was almost identical with the one he had described, only it was drawn the other way across the blackboard. Mr. Weighton asked whether they steam the largest size of engines on the erecting table. They had steamed all sizes that they had built so far, and they would during that week steam a set of 1,400 horse-power triple expansion engines on the erecting table. They had no difficulty in running them at 70 or 80 revolutions per minute, and they procured the steam from their factory boilers. Seeing the engines were run quite light, and produced for themselves a high vacuum, their chief difficulty was to regulate the admission of steam so as to admit a sufficiently small quantity to prevent the engines running too fast. The vacuum always extended right through to the high pressure engine, so that the initial steam had to be wiredrawn down to a pressure considerably below the atmosphere on its entrance to the high pressure cylinder. With reference to the shop girders, it was found the cost was almost exactly the same whether the fish-bellied or parallel type were adopted, and he greatly preferred the fish-bellied type, mainly because when overhead cranes were started or stopped in their cross traverse with heavy loads there was a tendency for the shop girders to be thrown over or collapsed sideways; and when parallel girders were used this force acted with a leverage corresponding to the whole depth of the girder; but with the fish-bellied girder the leverage was reduced to half, because the height from the crane rail to the seat of the girder on the column top

was only half the full depth of the girder. This tendency to instability sideways was also the reason why he had adopted double webs in the girders. The height in the erecting shop and boiler shop under the cranes was 32 feet clear, which they had found ample. The cost of concrete piers from a good strong mixture of concrete, when compared with that of adding to the length of the cast-iron columns, was found to show a small difference in favour of the columns, and this plan had several distinct advantages. For instance, near the foundry pits it was safer and better to carry the column down, and in the engine shop the large shoes and piers, if near the surface, would have been a great inconvenience in arranging machinery foundations, a difficulty that was entirely absent in the plan adopted. With regard to the estimation of the maximum load on the girders, this, of course, varied with the conditions existing in each particular bay. For the transverse crane girders the crane was supposed to be in the middle of the shop sustaining its maximum working load. For the longitudinal girders the end carriage of the heaviest crane contemplated was supposed to be in the middle of a longitudinal girder, and the crab close up to the same end of the transverse girders, and sustaining the maximum working load. The load on column bases was taken to include that due to a crane on each side, close to the column, and each sustaining its maximum load, the weight of girders and roof being added. Referring to Mr. Johnstone's query regarding the time vessels were kept at the engine works, the five days named did not include all night work, but certainly did include some overtime. The five days included shipping the whole of the machinery and boilers, setting fair and fixing, making all pipe connections, and completing the platforms and gratings, sufficiently to enable the engines to be steamed, and the ship to be returned under her own steam to the shipyard, so that the shipbuilders could proceed with the finishing of the ship; the engineers following the ship to the shipyard, to complete the painting and general finishing of their work in the engine room. He begged to thank the meeting generally for the patient manner in which his remarks had been listened to, and especially those gentlemen who had taken part in the discussion for their extremely kind criticisms.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886-87.

PROCEEDINGS.

FOURTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON THURSDAY EVENING, FEBRUARY 3RD, 1887.

W. THEO. DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the Minutes of the last General Meeting, held in Sunderland, on December 8th, 1886, which were approved by the members present, and signed by the President.

The ballot for new members having been taken, the President appointed Messrs Stirzaker and McKay to examine the voting papers, and the following gentlemen were declared elected:—

MEMBERS.

Ash, Mortimer W., Ashfield Villa, Heaton Road, Heaton.
Bell, John, Messrs. Northern Marine Engineering Co., South Shields.
Carr, Thomas, Messrs. Carr & Co., Engineers, Sunderland.
Halley, David, Messrs. Burmeister & Wains, Maskin-og Skibsbyggeri, Copenhagen, Denmark.
Scotson, Alfred, 10, Holmeside, Sunderland.
Tatham, Stanley, Messrs. Hawks, Crawshay, & Sons, Gateshead.
Thompson, Charles, 9, Dean Street, Newcastle.

GRADUATES DESIRING TO BECOME MEMBERS.

Collier, Percy N., Hurworth-on-Tees, Darlington.
Toomer, Chas. Reynolds, 26, North View, Heaton.

ASSOCIATE.

Maughan, William, Westmorland Road, Newcastle.

GRADUATES.

Barnes, William, 6, Elmwood Street, Sunderland.
Coull, Alexander B., 43, Stanley Street W., North Shields.

The PRESIDENT said, before proceeding with the paper, it was his melancholy duty to refer to the serious loss which that Institution had sustained through the death of one of its most energetic members. Mr. Ivan Mavor, whose death they now deplored, was one of the most prominent and active members they had. As a member of the Council he had proved that he had the interests of the Institution deeply at heart, for he was one of the most regular attendants at all their meetings. Personally, he had only known Mr. Mavor for a few months, but even in that short time he could see that, had he been spared, he would have continued to take a very prominent position in the Institution, and have assisted in making it one of the most powerful in the country. To show the great interest which he took in all matters connected with the profession, as soon as the idea was broached that a committee should be formed to consult with the authorities of the College of Physical Science as to the best means of giving instruction in Engineering and Naval Architecture, he offered to read a paper on the subject. That paper he, fortunately, had just completed; but the Council thought that, under the circumstances, it was better not to read it as intended, but to print it in the Transactions. He believed that paper would have considerable weight in the discussions of the committee. There were many gentlemen in that room, he had no doubt, who were more intimately acquainted with Mr. Mavor than he was, and who would perhaps like to say a few words. He would only add that fortunately the Institution had many members of the same stamp as the late Mr. Mavor, and as long as it had such men as members and on its Council, he was satisfied that it would continue not only to maintain but also to improve its high position. He should be very glad to hear the remarks that any gentleman had to make.

Mr. STIRZAKER said, though he had rather some one else had spoken about Mr. Mavor, as he was one of his most intimate friends it was perhaps becoming of him to do so. He thought that the letter which appeared in the *Newcastle Chronicle* and in the *Journal* a few days after the accident told nearly everything which would be of interest to the Institution. That Mr. Mavor was a man of great ability was evidenced by the fact that though he was only in his 27th year, he had already, without any help, attained to a very high position, and he would, no doubt, have rapidly risen to the top of his profession. The Institution could ill afford to lose him. He had done much for it, and, had he lived, would have done more. There was a point connected with this subject which he would take that opportunity of mentioning. He had intended before doing so to have seen the President about it, but owing to the absence

that night of Mr. Weighton, who purposed acting with him, he had not. It seemed to them that the inquest upon the accident which occurred by petroleum on board the S.S. "Petriana" was very unsatisfactory. They had carefully read the account of the inquest as it had appeared in the Liverpool papers, in which it was very fully reported, and had come to the conclusion that the verdict of the jury was not in accordance with the evidence. The verdict stated that the men had lost their lives through burning; but the four who were found in the petroleum tank showed little sign of having been burned. There was a mystery about the accident which had not been cleared up, and they considered that an ordinary coroner's inquiry into the cause of such an accident was not sufficient. They recognised the fact that every new trade must have its victims, but thought that the scientific inquiry which ought to follow should result in such information as would be of substantial benefit to that trade. As far as they could see, if this matter were allowed to remain where it was, ten lives would have been sacrificed in vain. He did not know whether he was in order in bringing that before the General Meeting, but thought it desirable that the Council of the Institution should consider it. He was strongly of opinion that a thoroughly scientific inquiry should be held to investigate the cause of the accident.

Mr. Macoll said, as one who had been associated on the Council with Mr. Mavor since this Institution was first started, he could say he was always an earnest, active, and talented worker; indeed, the example he had set during that time was a bright and worthy one for each and all to follow. He was sure they all felt his loss very much; and it was very desirable that the number of such members should be increased in this Institution. As the carriage of oil in bulk promised soon to assume considerable importance, it seemed a pity that a great deal of the knowledge and warning that might have been derived from the sacrifice they deplored was likely to be lost or ignored owing to the somewhat incomplete manner in which the inquiry into the late disaster had terminated. They were told there was good in everything, but if there was any good in that catastrophe in the way of instruction it had not been laid down in a way conducive to the protection and safety of any who might be engaged in a similar manner. It was proper from many considerations that the causes of the catastrophe should be more thoroughly investigated and laid down. At present all that seemed defined was the danger of naked lights, especially when testing. A great deal more ought to be known; and, primarily, under ordinary circumstances, what kind of lights are safe and reliable, as well as under what

conditions would the lights which might be safe under ordinary circumstances become dangerous? What effect would variations of temperature, ventilation, foggy weather, and so on produce? These were questions demanding consideration. He did not know whether they as an Institution had any *locus standi* in the individual case before them, but he considered, even from a humanitarian point of view, they, as an Institution, had fair scope to ask, and, if necessary, ascertain and formulate some more definite information than had hitherto been afforded. The whole matter had certainly been very distressing, and as it at present stood was very incomplete and unsatisfactory. They ought to have derived some very instructive lessons, but these lessons, warnings, or cautions had not as yet been put before them in that intelligent and instructive manner which he considered the subject deserved.

The PRESIDENT said he was under the impression that the deaths had been caused by burning, but from what Mr. Stirzaker had said there seemed to be a considerable doubt upon the subject. He thought it might have some weight if that meeting passed a resolution requesting the Council to take the matter up.

Mr. STIRZAKER then proposed, "That the Council of the Institution shall examine the evidence relating to the explosion on board the S.S. 'Petriana,' at Birkenhead, on the 26th December last, with the finding of the coroner's jury thereon, and that it take whatsoever steps it may deem desirable to obtain a more thorough investigation into the cause of the accident."

Mr. SANDISON said, as an old friend of Mr. Mavor's he had much pleasure in seconding the resolution.

On being put to the meeting it was carried unanimously.

Mr. HENRY FOSTER read a synopsis of the following paper "On 'The Principle of Work' in relation to the Strength of Materials, and the Fallacy of 'The Accepted Theory' of the Strength of Hollow Steel Shafting:"—

ON "THE PRINCIPLE OF WORK" IN RELATION TO THE STRENGTH OF STRUCTURES, AND THE FALLACY OF "THE ACCEPTED THEORY" OF THE STRENGTH OF HOLLOW SHAFTING.

By HENRY FOSTER.

THE "principle of work" as applied to machines includes within itself a truth which has passed into a proverb, viz.,—"What is gained in power is lost in speed;" but in its widest sense includes the whole theory of equilibrium.

Of the universal application of this principle in regulating the behaviour of machines, we, as engineers, have constant proof, and the object of this paper is to draw attention to a series of experiments and investigations into the behaviour of materials under tensile, transverse, and torsional strain, illustrating the application of this principle to the calculation of the strength of structures; and further, to contrast the results indicated by this law, and those indicated by "the accepted theory," referring all discrepancies between the two to the actual test of experiment.

In applying this principle to materials, it is necessary to consider that any load brought to bear upon a structure produces a displacement of the ultimate particles of that structure, and that the load continues to move until arrested by the elastic resistances induced in the material. This movement representing the aggregate of the individual movements of the particles is measured by the elongation in the case of tensile strains, and by the deflection and arc of twist respectively in the case of transverse and torsional strains; and so long as the elastic limit of the material is not exceeded, the elongation, deflection, and arc of twist respectively are directly proportional to the loads applied.

Here, then, it will be observed, we have a fundamental statement of work:—a body moving against a resistance; the body being represented by the load, the movement by the elongation, deflection, or arc of twist, as the case may be, which it produces; and the resistance as that offered by the particles of the structure in resisting displacement, and it will be shown in the course of this paper that the work, as represented by the product of the load, and the distance through which it moves in

displacing the particles, is proportional to the volume or weight of the structure; the weight and nature of the structure thus becoming the gauge of its work-equivalent.

First Impressions of this Law.

While conducting a series of experiments some six years ago, at the Newburn Steel Works, for and on behalf of his employers, Messrs. John Spencer & Sons, on the ultimate strength and deflection of helical springs of various forms of cross section, with a view to ascertain the particular cross section giving the maximum deflection and the maximum load, the author noticed from tabulated results of the experiments, that no matter what the cross section might be, the product of the maximum deflection, and the load producing it, divided by the weight of the spring was practically constant; in other words, the work-equivalent of a helical spring was found to be directly proportional to its weight, and independent of its form of cross section.

The results obtained from these experiments being at variance with what the "accepted theory" would indicate, suggested the investigations which the writer has now the honour to lay before you.

Tensile Strain.

When a bar of steel or other elastic material of equal section throughout its length is placed under tensile strain, the immediate effect of such strain is to produce an elongation of the bar, and providing the elastic limit of the material is not exceeded, the elongation is directly proportional to the load applied multiplied by the length of the bar, and inversely proportional to the modulus of direct elasticity of the material multiplied by the cross sectional area resisting extension. The strength of the bar however is directly proportional to its cross sectional area multiplied by the maximum safe tensile stress per square inch of section which the material is capable of resisting.

Consider such a bar, and—

Let W = any load applied to the bar less than the elastic limit.
W_1 = the maximum safe load.
e = the elongation produced by W.
e_1 = the elongation produced by W_1.
E = the modulus of direct elasticity of the material.
f = the maximum safe tensile stress per square inch of section.
L = the length of the bar.
a = the cross sectional area of the bar.

All dimensions being taken in inches, and loads in pounds.

Then, from what has been advanced it follows that—

$$e = \frac{W \times L}{E \times a} \qquad (1)$$

substituting for (W) in formula (1) the safe load $W_1 = a \times f$, and reducing, the safe elongation is:—

$$e_1 = \frac{a \times f \times L}{E \times a} = \frac{f L}{E} \qquad (2)$$

and multiplying the safe elongation by the safe load, we obtain *twice* the amount of work obtainable from the bar, thus:—

$$\text{Work} \times 2 = \frac{f L}{E} \times a \times f = \frac{a \times L \times f^2}{E} \qquad (3)$$

But $a \times L$ = the volume of material in the bar—

$$\therefore \text{Work} = \tfrac{1}{2} \frac{\text{Volume} \times f^2}{E} \qquad (4)$$

That is the work-equivalent of a bar under tensile strain is equal to one-half the volume of material multiplied by the square of the safe stress per square inch divided by the modulus of direct elasticity.

Transverse Strain.

Having determined the work-coefficient of a bar under tensile strain, the following questions naturally suggest themselves :—

1st—Can the "principle of work" be applied in the case of beams under transverse strain ?

2nd—What relation does the work-coefficient of a bar under transverse strain bear to its work-coefficient under tensile strain ?

3rd—In the case of a beam of *symmetrical* cross section, is an alteration in the arrangement of material with respect to the neutral axis accompanied by an alteration in the work-coefficient of the beam per unit of weight ?

To prevent confusion, it is necessary here to remark that only *symmetrical* cross section beams, or those in which the neutral axis coincides with the centre of height of cross section, will be treated in this paper.

In dealing with question No. 1, take the simple illustration of a beam of uniform breadth and depth, supported at both ends and loaded in the centre, as in Fig. 1, Plate 18, or fixed at one end and loaded at the other, as in Fig. 2, Plate 18.

The strength of such a beam decreases with its length and increases with its breadth, both in direct proportion, and increases as the square of its depth ; the flexibility however varies as the cube of its length,

inversely as its breadth, and the cube of its depth; thus the flexibility increases in a much higher ratio than that expressing the reduction of strength with increase of length, but yet the product of the deflection and the load producing it bear a constant relation to the quantity of material used, providing the material is strained to the same limit of stress in all cases.

For example: Let us suppose our beam to be of unit length, giving unit deflection with unit load, and having unit weight, and strained to its maximum safe stress by the load which it supports. If now we *double* its length it will deflect *eight* times as much as before *with the same load*, but by doubling its length we have decreased its strength in proportion, and therefore it will only support *one-half* its former load, giving of course four times its original deflection.

Therefore: Load $\times$ Defn. $= \frac{1}{2} \times 4 = 2$.

and in order to obtain this product of 2 we have doubled the length of the beam and consequently doubled its weight.

We may carry our illustration further, and instead of *doubling* the *length* of the beam let us double its *depth*; it will now deflect *one-eighth* of its original amount *with the same load*, but it will safely support *four times* the load, giving $4 \times \frac{1}{8} = \frac{1}{2}$, the original deflection.

Therefore: Load $\times$ Defn. $= 4 \times \frac{1}{2} = 2$,

which has been obtained by doubling its depth, and consequently its weight as before.

The remaining case, in which the breadth of the beam may be increased, will be self-evident and therefore requires no further comment.

But the question might still be asked,—Will the "principle of work theory" apply if we make the beam of corrugated cross section, *still keeping it symmetrical?* And to satisfy the terms imposed by this question, experiments were made on plain and corrugated steel bars, Nos. 1, 2, 3, and 4, 5, 6 respectively (Fig. 3, Plate 19); and in order that the results of these experiments might be uniform and comparable, and not vitiated by structural irregularities of material, all the bars were rolled from one billet of spring steel, the bars being afterwards annealed by placing them in a furnace at a bright red heat, closing the damper, and allowing both furnace and test bars to cool gradually. When cold, the bars were tested by securely fixing them at one end and applying loads at the other, registering the deflections at the point of application of load, and removing the weights after each addition to ascertain "set;" the work-coefficients of the bars were then compared.

by dividing the product of the load and deflection corresponding with the elastic limit by the weight of the bar ; and although the values of—

$$\frac{\text{Load in lbs.} \times \text{Defn. in inches.}}{\text{Weight in lbs.}}$$

thus obtained are not so uniform as might be desired, yet the mean results of 8·484 for plain bars, and 8·406 for corrugated bars, show a very close agreement, and justify the conclusion that their respective work-equivalents are in reality the same.

In proceeding to consider question No. 2, we are met by what Professor Unwin designates "The old puzzle about the strength of beams" (*Engineer*, Oct. 29, 1886), which may be described as follows :—

The ordinary theory of transverse strength leads to the equation—

$$M = fZ. \qquad (1)$$

Where M represents the bending moment, f the stress at the edge of the beam, and Z the modulus of section ; and it has long been known that a considerable discrepancy exists between the calculated tensile stress (f) on the extreme fibres of rectangular cross section beams, corresponding with their elastic and ultimate strength, and that obtained from experiments on the elastic and ultimate tensile strength of the material ; and it has further been noticed that the discrepancy here referred to is a maximum for rectangular cross section beams, and gradually decreases as the cross section assumes the girder form, until in the instance of a thin plate girder it is practically *nil*.

This discrepancy has often been discussed, and various theories have been advanced to account for it, such as, "The lateral action of the fibres or particles on each other ;" "The alteration in position of the neutral axis due to variations in the amount of strain applied," etc., etc. ; and in a valuable paper communicated to the Institute of Civil Engineers, Mr. Benjamin Baker, M.Inst.C.E., advocates the following simple formula for estimating the amount of error for intermediate cross sections between girder and bar, and gives expression to his views on the "accepted theory" in the following terms :—

> The theory of transverse stress has engaged the attention of mathematicians for many years, and certain hypotheses have been, and still are, generally accepted, although every practical engineer knows that, in the majority of cases the calculated results based upon these hypotheses are widely at variance with those obtained by experiment * * * * *
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> The average results of a very large number of experiments show, that as regards deflection under transverse stress, a rail as a beam behaves exactly in accordance

with the ordinarily accepted theory, with this important distinction, that the maximum deflection within the elastic limit is greater than theory would indicate, by an amount ranging from 5 to 50 per cent., according to the cross section of the rail.

Experiments by Mr. W. H. Barlow,* F.R.S., President, Inst. C.E., on other descriptions of beams would have indicated such a conclusion, and that the increase in the elastic deflection, as in the elastic and ultimate strength must necessarily be included within the limits of 0 and 70 per cent., because the increase is *nil* in the instance of a steel plate girder with a thin web, and averages 70 per cent. in a solid bar of rectangular cross section. In estimating the probable increase in the case of a beam, such as a rail having a cross section between these two extremes of girder and bar, the first impulse naturally would be to assume that it would approach the limit of 70 per cent. in the same proportion as the section of the rail approached the solid rectangular bar, that is to say, that the increase would be 70 per cent., multiplied by the sectional area of the rail, and divided by the area of the enclosing rectangle.

This simple assumption the author has found to be sufficiently near the truth for all practical purposes, as it leads to equally useful results when applied to a 5-inch flange rail—the widest now rolled—and to a bull-headed rail with a 2-inch bottom flange * * * * *

As regards the possibility of substituting for the practical experience now indispensable in a designer, a general theory of transverse strength, universally applicable and wholly satisfactory from a scientific point of view, the author is not at all sanguine.

A careful observation of the behaviour of structures of every class under stress has satisfied him that sooner or later, in every instance, a stage in the investigation is arrived at, where the general theory becomes valueless and even dangerous, except in the hands of the experienced engineer.—*Inst. of Civil Eng. Proc., Vol. LXII.*

These views candidly expressed by one of our greatest engineers, and indicating the amount of error between the actual and calculated strength of beams of varying cross section, have an important bearing on the "principle of work" theory; yet, while the actual transverse strength of a rectangular beam is here given as 70 per cent. more than theory would indicate, it is interesting to add that Mr. D. K. Clark places the increase of strength at 75 per cent., or a mean for the two observers of 72·5; in any case, however, the existence of an element of strength amounting in the case of rectangular cross section beams to over 70 per cent. more than "accepted theory" indicates, would seem to suggest the necessity of further investigation; although in applying the "principle of work" to the solution of the strength of beams, it soon becomes apparent that this discrepancy is absolutely necessary in order that the "principle of work" theory may be true.

* Phil. Transactions, Royal Society, 1855-57.

To illustrate this subject, let us consider the simple case of a beam of uniform rectangular cross section throughout its length, fixed at one end and loaded at the other, as in Fig. 2, Plate 18. Bisect the depth, C, D, at O, and draw the horizontal line O, P; then, since the beam is deflected under the load (W), the upper half above the line O, P, is extended, and the lower half compressed; and providing the moduli of elasticity of the material in tension and compression are equal, the elongation and compression respectively increase uniformly from zero at the central point O, to a maximum at the upper and lower surfaces C and D; and the proportional increase may be represented by the triangles C, O, E, and F, O, D, in which the lengthening and shortening of the fibres at any given height is represented by horizontal lines drawn across the triangles.

The horizontal tensile stress in the upper half, and the compressive stress in the lower half of the beam also increase uniformly from the central point O, where they are zero, to the upper and lower surfaces at C and D, and since the stresses in the fibres and the deflection of the beam are directly proportional to the load applied, it follows that if we consider C, O = O, D, to represent the load W, and C, E = F, D, to represent the deflection, then the triangles C, O, E and F, O, D, will represent the work done by the beam in tension and compression respectively, but the triangles C, O, E, and F, O, D, are together equal to the parallelogram C, E, O, G, therefore the parallelogram C, E, O, G, equal in height to half the depth of the beam, represents the total work done; from which it would appear that the material in a rectangular beam under transverse strain has only one-half the work-coefficient of the same material under tensile strain; but the work-coefficient of material under tensile strain is given by the formula—

$$\text{Work} = \tfrac{1}{2}\,\frac{\text{Volume} \times f^2}{\text{E}}. \qquad (2)$$

therefore, the work-coefficient of a rectangular cross section beam, in which the material is distributed to the best advantage, will be—

$$\text{Work} = \tfrac{1}{4}\,\frac{\text{Volume} \times f^2}{\text{E}} \qquad (3)$$

We are now in a position to investigate the work-coefficient of a rectangular cross section beam by the "accepted theory," and to compare the result obtained with that given by the "principle of work" in the case of a beam fixed at one end and loaded at the other, as in Fig. 2, Plate 18. For this purpose—

Let L = the length of the beam.

b and h = the breadth and depth respectively.

W = any load applied at the extreme end less than the elastic limit.

W_1 = the maximum safe load.

E = the modulus of elasticity of the material.

f = the maximum safe tensile stress per square inch of section.

f_1 = the maximum safe transverse stress per square inch, [modulus of rupture].

$I = \frac{bh^3}{12}$ = { the moment of inertia of the cross section of the beam.

$Z = \frac{bh^2}{6}$ = the modulus of section ("accepted theory").

d = the deflection produced by any load (W) at its point of application.

d_1 = the deflection produced by the safe load (W_1).

Vol. = the volume of material in the beam.

All dimensions being taken in inches, and loads in pounds.

Then, so long as the beam is uniform in cross section throughout its length, the deflection at the point of application of the load is given by the formula—

$$d = \frac{WL^3}{3EI} = \frac{4WL^3}{Ebh^3} \qquad (4)$$

and here it is necessary to remark, as pointed out by Mr. Baker in the case above cited, that the actual *deflection* of a beam is in accordance with that indicated by "accepted theory."

The safe load (W_1) capable of being supported by the beam, *according to "accepted theory"*—

$$= W_1 = \frac{fZ}{L} = \frac{fbh^2}{6L} \qquad (5)$$

Substituting the safe load given by formula 5 for W in formula 4, and reducing, we obtain the theoretical safe deflection, thus :—

$$d_1 = \frac{4fbh^2L^3}{6bh^3EL} = \tfrac{2}{3}\frac{L^2f}{hE} \qquad (6)$$

and multiplying the safe deflection thus obtained by the theoretical safe load, we obtain *twice* the theoretical safe amount of work, thus :—

$$\text{Work} \times 2 = \tfrac{2}{3}\frac{L^2f}{hE} \times \frac{fbh^2}{6L} = \tfrac{1}{9}\frac{bhLf^2}{E} \qquad (7)$$

But $b \times h \times L$ represents the volume of material in the beam, therefore formula 7 becomes—

$$\text{Work} \times 2 = \tfrac{1}{6} \frac{\text{Vol.} f^2}{E} \qquad (8)$$

and the same *theoretical* work-equivalent is obtained whether we consider our uniformly rectangular cross section beam as fixed at one end and loaded at the other, or supported at both ends and loaded in the middle; the safe deflection in the latter case being proportionally less, while the safe load is proportionally more. As a matter of fact however the actual value of (Work × 2) as determined by experiment is—

$$\text{Work} \times 2 = \tfrac{1}{3} \frac{\text{Vol.} f^2}{E} \qquad (9)$$

or three times the theoretical value.

It will however be observed that the material in a beam of the form under consideration is not distributed to the best advantage, since the modulus of section (Z) at any given cross section is not proportional to the bending moment at that section. The material can be distributed to the best advantage, still maintaining the same volume, by making the beam of uniform width throughout its length, and of variable depth as shown in Fig. 4, Plate 19, the curve forming the lower outline of the beam being parabolic, and the volume of material $= \frac{2}{3} bhL$.

In a beam fulfilling these conditions, the theoretical deflection at the point of application of load is given by the formula—

$$d = \frac{WL^3}{2EI} = \frac{6WL^3}{Ebh^3} \qquad (10)$$

while the theoretical safe load is—

$$W_1 = \frac{fZ}{L} = \frac{fbh^2}{6L} \qquad (11)$$

Substituting the safe load W_1, for W in formula 10, and reducing, we obtain the safe deflection, thus—

$$d_1 = \frac{6L^3bh^2f}{6Ebh^3L} = \frac{L^2f}{Eh} \qquad (12)$$

which being multiplied by the safe load, gives *twice* the work-coefficient as before.

$$\text{Therefore—Work} \times 2 = \frac{L^2f}{Eh} \times \frac{bh^2f}{6L} = \tfrac{1}{6} \frac{bhLf^2}{E} \qquad (13)$$

but the volume represented by $\frac{2}{3} bhL$ in formula 13 was made equal to that of the beam of uniform cross section, and therefore formula 13 becomes

$$\text{Work} \times 2 = \tfrac{1}{4} \frac{\text{Vol.} f^2}{E} \qquad (14)$$

from which it follows that the accepted theoretical transverse work-coefficient of materials distributed to the best advantage in beams of rectangular cross section is given by the formula—

$$\text{Work} = \tfrac{1}{8}\frac{\text{Vol.}\,f^2}{\text{E}} \qquad (15)$$

In the absence of experimental data obtained from beams of this particular form, the theoretical work-coefficient here given cannot be compared with results obtained from direct experiment; but, considering that in the beam of uniform depth only $\frac{2}{3}$ of the material is used to advantage, giving a theoretical value of—

$$\text{Work} \times 2 = \frac{1}{9}\frac{\text{Vol.}\,f^2}{\text{E}}, \qquad \text{(see Formula 8)}$$

it is reasonable to assume that when all the material is advantageously used the work-coefficient will be increased in proportion, and give a value of—

$$\text{Work} \times 2 = \frac{1}{9} \times \frac{3}{2} = \frac{1}{6}\frac{\text{Vol.}\,f^2}{\text{E}}; \qquad (16)$$

and therefore—

$$\text{Work} = \frac{1}{12}\frac{\text{Vol.}\,f^2}{\text{E}}, \qquad (17)$$

while the tensile work-coefficient has been shown to be—

$$\text{Work} = \frac{1}{2}\frac{\text{Vol.}\,f^2}{\text{E}} \qquad (18)$$

giving a relationship of tensile work-coefficient ÷ transverse work-coefficient of 6 to 1.

But reasoning from analogy, it has previously been shown that the "principle of work" theory would give a relationship of 2 to 1, and a transverse work-coefficient of—

$$\text{Work} = \frac{\text{Vol.}\,f^2}{4\text{E}} \text{ instead of } \frac{\text{Vol.}\,f^2}{12\text{E}}$$

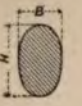
from which it follows that the *transverse* work-coefficient thus determined is only one-third the amount required to fulfil the conditions imposed by the "principle of work;" and comparing formulæ 17 and 18 with a view to account for this discrepancy, it is evident that if—

$$f^2 \times 3 = f_1^2, \text{ and consequently, } f\sqrt{3} = f_1$$

or in other words, if the transverse safe stress is 1·732 times the tensile safe stress, then these imposed conditions are fulfilled; and here it is necessary to remember, as previously pointed out, that the mean results of Messrs. Baker and Clark's observations give the transverse safe stress as 1·725 times the tensile safe stress, thus showing a remarkable agreement with the result indicated by the "principle of work."

In the preceding investigations it has been assumed that the moduli

TABLE OF THEORION THROUGHOUT THEIR LENGTH;

No.	Section.		Mom	eflection at Point of Application of Load $= d_1 = \frac{W_1 L^3}{3EI}$.	Twice the Work Co-efficient.
1	Square.			$\frac{2}{3}\frac{L^2 f}{ES}$	$\frac{1}{9}\frac{\text{Vol. } f^2}{E}$
2	Rectangle.			$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{9}\frac{\text{Vol. } f^2}{E}$
3	Circle.			$\frac{2}{3}\frac{L^2 f}{ED}$	$\frac{1}{12}\frac{\text{Vol. } f^2}{E}$
4	Ellipse.			$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{12}\frac{\text{Vol. } f^2}{E}$
5	Hollow Square.		$\frac{1}{12}$	$\frac{2}{3}\frac{L^2 f}{ES}$	$\frac{1}{9}\frac{(S^4-s^4)f^2L}{S^2E}$
6	Hollow Circle.		$\frac{\pi}{64}$	$\frac{2}{3}\frac{L^2 f}{ED}$	$\frac{1}{12}\frac{\pi}{4}\frac{(D^4-d^4)f^2L}{D^2E}$
7	Hollow Rectangle.		$\frac{1}{12}$	$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{9}\frac{(BH^3-bh^3)f^2L}{H^2E}$
8	Hollow Ellipse.		$\frac{\pi}{64}$	$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{12}\frac{\pi}{4}\frac{(BH^3-bh^3)f^2L}{H^2E}$
9	Flanged Girder.		$\frac{1}{12}$	$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{9}\frac{(BH^3-bh^3)f^2L}{H^2E}$
10	Flanged Girder.		$\frac{1}{12}$	$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{9}\frac{(BH^3+bh^3)f^2L}{H^2E}$
11	Pierced Rectangle.		$\frac{1}{12}$	$\frac{2}{3}\frac{L^2 f}{EH}$	$\frac{1}{9}\frac{B(H^3-h^3)f^2L}{H^2E}$

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of elasticity in tension and compression are equal, which although not absolutely true in all cases, is very approximately true for ordinary materials of construction; at the same time it is essential to keep in view the fact that this variation, combined with the variations in the elastic strength of similar bars cut from the same material, is sufficient to account for variations in their work-equivalents.

We now come to question No. 3, viz.,—In the case of a beam of *symmetrical* cross section, is an alteration in the arrangement of material with respect to the neutral axis accompanied by an alteration in the work-equivalent of the beam per unit of weight?

The "accepted theory" answers Yes! The "principle of work" No! And in order to arrive at the truth for beams of various cross section, let us refer all observed discrepancies between the two to the test of actual experiment. With this object in view consider Table No. 1 representing the accepted theoretical safe loads, safe deflections, and work-coefficients of various *symmetrical* cross section beams, which for simplicity are considered as of uniform section throughout their length, fixed at one end and loaded at the other.

Considering sections No. 1 and 2, Table No. 1, it has already been shown that according to the "principle of work"—

$$f\sqrt{3} = f_1, \text{ and therefore } \frac{f_1}{\sqrt{3}} = f.$$

Where f and f_1 respectively represent the tensile and transverse elastic stresses of the material f_1, being determined by the theoretical formula $f_1 = \frac{6\ \mathrm{WL}}{\mathrm{BH}^2}$, and referring to Tables Nos. 2 and 3, giving the results of experiments on the tensile and transverse strength of pieces of steel cut from the same bar, we find a striking example of the truth of this relationship, since both the tensile elastic and maximum stresses when multiplied by $\sqrt{3}$ or 1·732, give a result closely corresponding with the transverse elastic and ultimate stresses.

Note.—Preparation of Test-Pieces.—Considering that a comparison of the relative tensile and transverse strength of steel, and the relative strength of square and round bars depended upon the results of experiments recorded in Tables No. 2, 3, and 4, it was necessary that the material of which the test-pieces were made should be as uniform in structure as possible. A piece of steel of known uniform quality was therefore taken, and after being drawn down under the steam hammer, was afterwards rolled to 1¾ inches square, it being assumed that any structural irregularities left by the steam hammer would be taken out in the subsequent rolling. The whole of the test-pieces, both tensile and transverse, were then cut from one long bar, prepared as described, and afterwards machined to the dimensions given.

TABLE No. 2.

EXPERIMENTS MADE AT THE NEWBURN STEEL WORKS ON THE TENSILE STRENGTH OF SIX PIECES OF STEEL CUT FROM THE SAME BAR.

Mark of Test.	Size of Specimen in Inches.		Original Area in Square Inches.	Fractured Area in Square Inches.	Permanent Set Induced, Tons per Square Inch.	Maximum Stress, = Tons per Square Inch.	Contraction of Area Per Cent.	Elongation Per Cent. in Length of.				Appearance of Fracture.
	Length.	Diam.						2″	4″	5″	6″	
Q198	6	·759	·4524	·2827	16·775	27·137	37·51	32	26	25	22	Silky.
Q199	6	·755	·4477	·2780	16·453	27·420	37·90	32	26	25	22	,,
Q200	6	·759	·4524	·2780	16·282	27·137	38·55	34	26	25	22	,,
Q201	6	·760	·4536	·2827	16·239	27·065	37·67	34	27	26	23	,,
Q202	6	·757	·4500	·2724	16·865	27·281	39·46	34	28	27	24	,,
Q203	6	·759	·4524	·2724	16·775	27·137	39·78	34	28	26	22	,,
Mean	...	...	...	...	...	16·564	27·196					

Elastic Limit × $\sqrt{3}$ = (16·564 × 1·732) = 28·688 Tons per square inch
Maximum Stress × $\sqrt{3}$ = (27·196 × 1·732) = 47·103 ,, ,,

} Equivalent Transverse Stress for Bars of Square or Oblong Cross Section. (See Table 3.)

TABLE No. 3.

EXPERIMENTS MADE AT THE NEWBURN STEEL WORKS ON THE TRANSVERSE STRENGTH OF SIX PIECES OF SQUARE STEEL CUT FROM THE SAME BAR AS THOSE RECORDED IN TABLE 2.

Mark of Test.	Size of Specimen in Inches.			× D²	Distance between Supports = L.	Actual Load in Tons on Centre of Bar = W.		$f_1 = \frac{6LW}{4BD^2}$.		Remarks.
	Length.	Breadth.	Depth.			Elastic Limit.	Maximum Strain.	Elastic Limit f_1.	Maximum Stress f_1.	
					Inches.					
ΔQ198	15	1·25	1·25	1·9531	10	3·75	6·16071	28·800	47·314	Drawn through supports.
ΔQ199	15	1·25	1·25	1·9531	10	3·70535	6·11607	28·457	46·972	,,
ΔQ200	15	1·25	1·25	1·9531	10	3·70535	6·16071	28·457	47·314	,,
ΔQ201	15	1.25	1·25	1·9531	10	3·75	6·16071	28·800	47·314	,,
ΔQ202	15	1·25	1·25	1·9531	10	3·70535	6·11607	28·457	46·972	,,
ΔQ203	15	1·25	1·25	1·9531	10	3·70535	6·16071	28·457	47·314	,,
Mean	...	...	...	...	...	...	...	28·571	47·200	

Elastic Limit, $f_1 \div \sqrt{3}$ = (28·571 ÷ 1·732) = 16·495 Tons per square inch } Equivalent Tensile Stress.
Maximum Stress, $f_1 \div \sqrt{3}$ = (47·200 ÷ 1·732) = 27·251 ,, ,, } (See Table 2.)

TABLE No. 4.

EXPERIMENTS MADE AT THE NEWBURN STEEL WORKS ON THE TRANSVERSE STRENGTH OF SIX PIECES OF ROUND STEEL, CUT FROM THE SAME BARS AS THOSE RECORDED IN TABLES 2 AND 3.

Mark of Test.	Size of Specimen in Inches.		D^3.	Distance between Supports = L.	Actual Load in Tons on Centre of Bar = W.		Accepted Theory. $f_1 = \frac{WL}{\frac{\pi}{32} D^3 \times 4.}$		Principle of Work. $f_1 = \frac{WL}{\frac{\pi}{16\sqrt{3}} D^3 \times 4.}$		Remarks.
	Length.	Diameter.			Elastic Limit.	Maximum Strain.	Elastic Limit f_1.	Maximum Stress f_1.	Elastic Limit f_1.	Maximum Stress f_1.	
				Inches.							
△Q198[a]	15	1·25	1·9531	10	2·54464	4·19642	33·177	54·713	28·731	47·381	Drawn through supports.
△Q199[a]	15	1·25	1·9531	10	2·5	4·19642	32·595	54·713	28·227	47·381	"
△Q200[a]	15	1·25	1·9531	10	2·54464	4·15178	33·177	54·131	28·731	46·877	"
△Q201[a]	15	1·25	1·9531	10	2·54464	4·24107	33·177	55·165	28·731	47·885	"
△Q202[a]	15	1·25	1·9531	10	2·45535	4·15178	32·013	54·131	27·723	46·877	"
△Q203[a]	15	1·25	1·9531	10	2·5	4·19642	32·595	54·713	28·227	47·381	"
Mean	...	...	...	...	...	...	32·789	54·594	28·395	47·297	

"Principle of Work" Elastic Limit f_1 $\div \sqrt{3}$ = (28·395 ÷ 1·732) = 16·394 Tons per square inch } Equivalent Tensile Stress.
" " Maximum Stress f_1 $\div \sqrt{3}$ = (47·297 ÷ 1·732) = 27·307 " " } (See Table 2.)

Comparing the work-coefficients of Nos. 1 and 3, Table 1, for square and round sections respectively, it might be inferred from the relationship given that the work-equivalent per unit of volume is greater for square than for round beams; but it will be seen from a comparison of the results of transverse tests of square bars given in Table 3 with those of round bars given in Table 4, that $f_x^2 \div 9, = f_y^2 \div 12$, where f_x and f_y are the elastic or ultimate transverse stresses for square and round bars respectively, calculated by accepted rules. The actual work-coefficients being thus proved to be equal, although otherwise indicated by "accepted theory."

In proceeding to apply the "principle of work" theory to the solution of the more complex forms (Nos. 5 to 11, Table No. 1) wherein the material is taken from the central portions of the respective cross sections, it will be observed that the formulæ representing their work-coefficients do not express the work done in terms of material used; thus for instance, in Section No. 5, representing a square tube, the expression—

$$\frac{1}{9}\frac{(S^4 - s^4) f^2 L}{S^2 E}$$

should have been—

$$\frac{1}{9}\frac{(S^2 - s^2) f^2 L}{E} = \frac{1}{9}\frac{\text{Vol.} f^2}{E}$$

in order that the work-coefficient might be proportional to the volume of material used, and it will be shown that the difference between these two expressions accounts for the discrepancies known to exist between the actual transverse strength of square tubes and that calculated by the "accepted theory;" and the same may be said of all the other cases of symmetrical cross section beams wherein the theoretical work-coefficient determined as explained is not proportional to the volume of material in the beam; and therefore it may be inferred that the known transverse strength of a square bar may be made the basis of comparison for determining the transverse strength of complex symmetrical cross section beams, from which in turn may be computed the tensile strength of the material, in accordance with the relationship already shown to exist between the tensile and transverse strength of a square bar.

As previously stated, the actual deflection of a beam of uniform breadth and depth at the point of application of load is in accordance with what the "accepted theory" would indicate; and therefore the entire discrepancy above referred to has to be accounted for on the assumption that the theoretical modulus of section Z is in error; and acting on this assumption, we may proceed to alter the formulæ expressing the moduli

of section Z for symmetrical cross section beams illustrated in Table 1, so that their work-equivalent may always be represented in terms of material used; and afterwards test the formulæ thus obtained by reference to actual experiments.

By referring to Table 1 it will be observed that the formula representing twice the work-coefficient of any beam is obtained by substituting the square of the theoretical safe load on the end of that beam in place of W in deflection formula—

$$d = \frac{W L^3}{3 E I}$$

and in order that the ultimate product for all symmetrical cross sections may equal—

$$\frac{1}{9} \frac{\text{Vol.} f_1^2}{E},$$

as in the case of a square bar, it follows that—

$$\frac{1}{9} \left(\frac{\text{Vol.} f_1^2}{E} \right) \div (\text{safe load})^2 = \frac{L^3}{3 E I}.$$

Therefore: $$\text{safe load} = \sqrt{\frac{(\text{area of cross section}) f_1^2 I}{3 L^2}},$$

and consequently $$Z_1 = \sqrt{\frac{(\text{area of cross section}) I}{3}};$$

the solid square bar thus becoming the basis of comparison for all symmetrical cross sections.

On this basis the annexed Table No. 5 of safe loads, safe deflections, moduli of resistance, and work-coefficients has been calculated, f_1 being in every case obtained by the ordinarily accepted formula—

$$f_1 = \frac{6 W L}{B H^2},$$

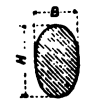
and represents the transverse stress (modulus of rupture) for a square bar fixed at one end and loaded at the other.

We are now in a position to apply the "principle of work" formulæ given in Table 5 to the estimation of stresses in beams of symmetrical cross section, and in order to show their general application, the following Tables, Nos. 6 to 11, of actual tests of beams have been added, in which the elastic and ultimate stresses have been calculated by "accepted theory," and also by the "principle of work," the results thus obtained being arranged side by side for facility of comparison; and bearing in mind that in the case of a rectangular bar—

$$\frac{\text{Transverse stress}}{\sqrt{3}} = \text{tensile stress},$$

the tensile stress thus computed has also been added.

TABLE OF SAFE DEFLECTION, AND OF UNIFORM CROSS SECTION

No.	Section.		Deflection at Point of Application of Load $= d_1 = \frac{W_1 L^3}{3EI}$.	Twice the Work-Coefficient.
1	Square.		$\frac{2}{3}\frac{L^2 f_1}{ES}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
2	Rectangle.		$\frac{2}{3}\frac{L^2 f_1}{EH}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
3	Circle.		$\frac{4}{3\sqrt{3}}\frac{L^2 f_1}{ED}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
4	Ellipse.		$\frac{4}{3\sqrt{3}}\frac{L^2 f_1}{EH}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
5	Hollow Square		$\frac{2}{3}\frac{L^2 s_1}{E\sqrt{S^2+s^2}}$	$\frac{1}{9}\frac{\text{Vol} f_1^2}{E}$
6	Hollow Circle.		$\frac{4}{3\sqrt{3}}\frac{L f_1}{E\sqrt{D^2+d^2}}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
7	Hollow Rectangle.		$\frac{1}{12}\frac{L^2(BH-bh)f_1}{\sqrt{(BH^3-bh^3)(BH-bh)}}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
8	Hollow Ellipse.		$\frac{\pi}{64}\frac{L^2(BH-bh)f_1}{E\sqrt{(BH^3-bh^3)(BH-bh)}}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
9	Flanged Girder.		$\frac{1}{12}\frac{L^2(BH-bh)f_1}{\sqrt{(BH^3-bh^3)(BH-bh)}}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
10	Flanged Girder.		$\frac{1}{12}\frac{L^2(BH+bh)f_1}{\sqrt{(BH^3-bh^3)(BH-bh)}}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$
11	Pierced Rectangle.		$\frac{1}{12}\frac{L^2\sqrt{(H^3-h^3)(H-h)}f_1}{E(H^3-h^3)}$	$\frac{1}{9}\frac{\text{Vol.} f_1^2}{E}$

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In comparing the stresses in symmetrical beams deduced by theoretical and "principle of work" formulæ respectively, let us consider the various cross sections illustrated in Tables Nos. 1 and 5, in their order of arrangement, Sections Nos. 1 and 2 having already being considered, no further comment is necessary.

Referring next to Section No. 3, representing a solid round beam, it will be observed that while the theoretical modulus of section Z is given as $\frac{\pi}{32} D^3$, its value, in order to comply with the "principle of work," should be $\frac{\pi}{16\sqrt{3}} D^3$, and in comparing the respective transverse stresses in Table No. 4, calculated from these two moduli, the truth of the latter expression becomes apparent, since the transverse stresses computed from this modulus agree with those obtained for the square bar, while the stresses computed from the theoretical modulus are much higher, although the material in both cases is the same; and here, as in the case of the square bar, it is only necessary to divide the "principle of work" transverse stress by $\sqrt{3}$, in order to obtain the tensile stress.

As a further illustration, Table No. 6 has been added, giving the results of experiments made by Mr. W. H. Barlow on the transverse strength of round cast iron beams, $2\frac{3}{16}$ inches and $2\frac{1}{2}$ inches diameter respectively, and although the *actual* tensile breaking strength of the metal from which these bars were made, as obtained from the mean of eight experiments, was only 8·307 tons per square inch, the mean tensile breaking stress on the extreme fibres obtained by the accepted theoretical formula, from the transverse experiments is 20·176 tons per square inch for the $2\frac{3}{16}$ inch bars, and 17·71 tons per square inch for the $2\frac{1}{2}$ inch bars, the comparative results given by the "principle of work" are 10·087 and 8·854 tons per square inch respectively.

Objection might here be taken to these "principle of work" results, on the ground that they are higher than the actual tensile tests; but this objection is met by the fact that under tensile strain a bar is strained throughout, while in the case of a bar of uniform cross section, supported at both ends and loaded in the middle, that part only which lies immediately under the load is strained to its maximum stress, the stresses gradually decreasing towards the supports; so that a slight defect occurring anywhere in the tensile bar would affect its result, while the transverse strength would only be affected when the flaw happened to occur in the lower portions of the bar immediately under the load.

For the ellipse Section No. 4, the theoretical and "principle of work" formulæ are given for comparison, although the writer has not been able to find any published results of experiments on beams of this section to which the respective formulæ could be referred.

Sections No. 5 and 6 of hollow square and hollow circular beams can be referred to the results of experiments on the transverse strength of cast iron tubes given in Table No. 7, and here it will be observed that while according to theory the mean tensile breaking stress on the extreme fibres is 11·507 tons per square inch for hollow square beams, and 12·582 tons per square inch for hollow circular beams, the comparative tensile stresses in tons per square inch given by the "principle of work" are 8·344 and 8·084 respectively; the latter results, it will be admitted, being more in accordance with the ordinary tensile strength of cast iron than the former.

Sections No. 7 and 8 are illustrated by the results of experiments on the transverse strength of hollow rectangular and hollow oval cast iron tubes given in Table No. 8. Here also the mean tensile breaking stresses of 7·378 tons per square inch for rectangular tubes, and 9·36 tons per square inch for oval tubes given by the "principle of work," agree very well with the tensile strengths of ordinary samples of cast iron; while the mean tensile breaking stress on the extreme fibres of 10·832 tons per square inch given by "accepted theory" for hollow rectangular tubes is high, and that of 15·598 tons per square inch for hollow oval tubes is outside the limit of tensile strength of ordinary cast iron.

Table No. 9 gives the results of experiments by Mr. W. H. Barlow on the transverse strength of cast iron beams, which serve to illustrate the relative stresses obtained by different formulæ for Sections No. 9 and 10; here, too, the mean tensile breaking stresses in tons per square inch on outer fibres of 16·752 and 19·178 given by "accepted theory" are never attained in actual experiments on the tensile strength of cast iron, and although the comparative results of 11·619 and 10·036 tons per square inch respectively given by the "principle of work" are high, it is well known that with thin sections like those under consideration, in which the metal becomes chilled, these results are obtainable.

Section No. 9 is further illustrated by the experiments made by Mr. D. Kirkaldy and by Mr. B. Baker on the transverse strength of rolled joists given in Table No. 10; and here also, it will be admitted, that the actual tensile stresses on the extreme fibres corresponding with the elastic limit and buckling loads respectively are much better represented by the "principle of work" results than those given by the "accepted theory."

TABLE No. 6.

SUMMARY OF EXPERIMENTS ON THE TRANSVERSE STRENGTH OF ROUND CAST IRON BARS.—BY MR. W. H. BARLOW.

Form of Section.	Number.	Span in Inches.	Diameter of Bar in Inches.	Breaking Weight in Pounds on Centre of Bar.	Area of Cross Section in Square Inches.	Accepted Theory. $Z = \frac{\pi}{32} D^3$.	Accepted Theory. Breaking Stress in Tons per Square Inch on Extreme Fibres.	Principle of Work. $Z_1 = \frac{\pi}{16\sqrt{3}} D^3$.	Principle of Work. Transverse Stress in Tons per Square Inch on extreme Fibres.	Principle of Work. Tensile Stress in Tons per Square Inch. $= \frac{\text{Trnsvrs. Strs.}}{\sqrt{3}}$
	1	60	2·20	3068	3·801	1·04531	19·654	1·20705	17·020	9·826
	2	60	2·20	2988	3·801	1·04531	19·141	1·20705	16·576	9·570
	3	60	2·19	3388	3·767	1·03112	22·002	1·19067	19·054	11·001
	4	60	2·20	3228	3·801	1·04531	20·679	1·20705	17·908	10·338
	5	60	2·19	2988	3·767	1·03112	19·405	1·19067	16·804	9·702
Mean ...	...	...	...	...	...	...	...		17·472	10·087
	1	60	2·52	4283	4·987	1·5710	18·256	1·8141	15·809	9·127
	2	60	2·52	4283	4·987	1·5710	18·256	1·8141	15·809	9·127
	3	60	2·52	4003	4·987	1·5710	17·062	1·8141	14·776	8·531
	4	60	2·51	4003	4·948	1·5523	17·267	1·7925	14·953	8·633
Mean ...	...	...	...	...	...	...	...		15·336	8·854

TABLE No. 7.

EXPERIMENTS MADE BY MR. EDWIN CLARK ON THE TRANSVERSE STRENGTH OF SQUARE AND ROUND CAST IRON TUBES.

Form of Section.	Number.	Span in Inches.	Breaking Weight on Centre in Tons = Load + ⅛ Weight of Tube.	Dimensions of Tube in Inches.		Area of Cross Section in Square Inches.	Accepted Theory.		Principle of Work.		
				S.	s.		$Z=\frac{(S^4-s^4).}{6S}$	Breaking Stress in Tons per Square Inch on Extreme Fibres.	$Z_1=\frac{1}{6}(S^2-s^2)\sqrt{S^2+s^2}.$	Transverse Breaking Stress in Tons per Square Inch on Extreme Fibres.	Tensile Stress in Tons per Sq. In. Transvrse Stress $\div \sqrt{3}$
	1	72	2·067	3·125	2·375	4·125	3·389	10·978	2·698	13·790	7·961
	2	72	2·417	3·125	2·375	4·125	3·389	12·837	2·698	16·125	9·310
	3	72	2·016	3·125	2·375	4·125	3·389	10·707	2·698	13·449	7·763
Mean ...	...	...	...	...	...	...	...	11·507	.....	14·454	8·344
				D.	d.		$Z=\frac{\pi}{32}\frac{(D^4-d^4)}{D}$		$Z_1=\frac{\pi}{16\sqrt{3}}(D^2-d^2)\sqrt{D^2+d^2}.$		
	1	72	2·104	3·875	3·125	4·0984	3·297	11·486	2·962	12·785	7·381
	2	72	2·434	3·875	3·125	4·0984	3·297	13·288	2·962	14·791	8·539
	3	72	2·375	3·875	3·125	4·0984	3·297	12·966	2·962	14·432	8·332
Mean ...	...	...	...	...	...	...	...	12·580	.....	14·002	8·084

TABLE No. 8.

EXPERIMENTS MADE BY MR. EDWIN CLARK ON THE TRANSVERSE STRENGTH OF CAST IRON RECTANGULAR AND OVAL TUBES.

Form of Section.	Number.	Span in Inches.	Breaking Weight on Centre in Tons = Load + ½ Weight of Tube.	Dimensions of Tube in Inches.				Total Area of Cross Section in Square Inches.	Accepted Theory.		Principle of Work.		
				H.	B.	h.	b.		$Z = \frac{(BH^3 - bh^3)}{6H}$	Breaking Stress in Tons per Square Inch on Extreme Fibres.	$Z_1 = \frac{1}{6}\sqrt{(BH^3 - bh^3)(BH - bh)}$	Transverse Breaking Stress in Tons per Square Inch on Extreme Fibres.	Tensile Stress in Tons per Sq. In. = Transverse Stress / $\sqrt{3}$
	1	72	2·216	4·041	2·208	3·291	1·458	4·1242	3·866	10·317	3·277	12·172	7·027
	2	72	2·276	4·041	2 208	3·291	1·458	4·1242	3·866	10·597	3·277	12·501	7·217
	3	72	2·466	4·041	2·208	3·291	1·458	4·1242	3·866	11·481	3·277	13·545	7·820
	4	72	2·349	4·041	2·208	3·291	1·458	4·1242	3·866	10·936	3·277	12·902	7·449
Mean	...	...	...	...	...	...	...	...	...	10·832	...	12·780	7·378
				H.	B.	h.	b,		$Z = \frac{\pi}{32}\frac{(BH^3 - bh^3)}{H}$		$Z_1 = \frac{\pi}{16\sqrt{3}}\sqrt{(BH^3 - bh^3)(BH - bh)}$		
	1	72	3·016	5·035	2·705	4·285	1·955	4·1174	3·7331	14·542	3·5916	15·115	8·726
	2	72	3·196	5·035	2·705	4·285	1·955	4·1174	3·7331	15·410	3·5916	16·017	9·247
	3	72	2·934	5·035	2·705	4·285	1·955	4·1174	3·7331	14·146	3·5916	14·704	8·489
	4	72	3·431	5·035	2·705	4·285	1·955	4·1174	3·7331	16·543	3·5916	17·195	9·927
	5	72	3·219	5·035	2·705	4·285	1·955	4·1174	3·7331	15·521	3·5916	16·132	9·314
	6	72	3·615	5·035	2·705	4·285	1·955	4·1174	3·7331	17·430	3·5916	18·117	10·460
Mean	...	...	...	...	...	...	...	...	...	15·598	...	16·213	9·360

TABLE No. 9.

SUMMARY OF EXPERIMENTS ON THE TRANSVERSE STRENGTH OF CAST IRON BEAMS.—BY MR. W. H. BARLOW.

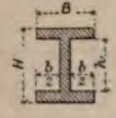
Form of Section.	Number.	Span in Inches.	Breaking Weight on Centre in Pounds.	Dimensions of Beam in Inches.				Total Area of Cross Section in Square Inches.	Accepted Theory.		Principle of Work.		
				B.	H.	b.	h.		$Z=\frac{(BH^3-bh^3)}{6H}$	Breaking Stress in Tons Per Square Inch on Extreme Fibres.	$Z_1=\frac{1}{6}\sqrt{(BH^3-bh^3)(BH-bh)}$	Transverse Breaking Stress in Tons per Square Inch on Extreme Fibres.	Tensile Stress in Tons per Square Inch. Transverse Stress. $=\frac{}{\sqrt{3}}$
	1	48	3310	1·99	1·97	1·44	·98	2·51	1·1725	15·123	·9829	18·049	10·415
	2	48	3560	1·97	2·00	1·50	1·00	2·47	1·1883	16·049	·9891	19·281	11·132
	3	48	3735	2·02	2·01	1·54	1·00	2·52	1·2324	16·235	1·0200	19·616	11.325
	4	48	3910	2·07	2·08	1·54	·97	2·81	1·3799	15·179	1·1594	18·066	10·430
	5	48	4528	2·02	2·07	1·50	1·01	2·67	1·3181	18·403	1·1019	22·013	12·709
	6	48	4563	2·04	2·07	1·57	1·05	2·57	1·3105	18·652	1·0779	22 678	13·093
	7	48	4423	2·09	2·06	1·56	1·02	2·71	1·3442	17·627	1·1183	21·188	12·233
Mean ...	...	...	...	...	...	...	...	...	...	16·752		20·126	11·619
				B.	H.	b.	h.		$Z=\frac{(BH^3+bh^3)}{6H}$		$Z_1=\frac{1}{6}\sqrt{(BH^3+bh^3)(BH+bh)}$		
	1	48	2368	·98	1·97	1·00	·50	2·43	·6444	19·699	·7170	17·692	10·214
	2	48	2288	1·00	1·96	·96	·48	2·42	·6492	18·880	·7164	17·109	9·878
	3	48	3128	1·10	2·05	·92	·55	2·76	·7829	21·403	·8592	19·503	11·260
	4	48	2568	1·02	2·04	1·00	·51	2·59	·7183	19·152	·7953	17·298	9·987
	5	48	2420	1·06	2·06	·98	·50	2·67	·7596	17·067	·8344	15·537	8·970
	6	48	2648	1·02	2·05	1·02	·50	2·60	·7247	19·451	·8024	17·679	10·207
	7	48	2568	1·04	2·05	1·00	·52	2·63	·7398	18·595	·8153	16·873	9·741
Mean ...	...	...	...	...	...	...	...	...	...	19·178		17·384	10·036

TABLE No. 10.

Experiments on the Transverse Strength of Rolled Joists.

Mark.	Span in Feet.	Load on Centre = Tons.		Dimensions of Joist in Inches.				Total Area of Cross Section in Square Inches.	Accepted Theory.			Principle of Work.				
		Observed Elastic Limit.	Observed Buckling Load.	Depth.	Breadth.	Thickness of Web.	Mean Thickness of Flange.		$Z = \frac{BH^3 - bh^3}{6H}$	Stress in Tons per Square Inch on Extreme Fibres.		$Z_1 = \frac{1}{6}\sqrt{(BH^3 - bh^3)(BH - bh)}$	Transverse Stress in Tons per Square Inch on Extreme Fibres.		Tensile Stress = Transverse Stress / $\sqrt{3}$	
										Elastic Limit.	Buckling Load.		Elastic Limit.	Buckling Load.	Elastic Limit.	Buckling Load.
A	20	10·714	14·310	11·75	5·70	·60	·643	13·34	48·274	13·316	17·785	35·512	18·102	24·177	10·451	13·959
	10	21·428	32·450	11·75	5·70	·60	·643	13·34	48·274	13·316	20·166	35·512	18·102	27·413	10·451	15·827
B	20	8·482	11·445	9·85	4·60	·50	·804	11·50	35·542	14·318	19·320	25·903	19·647	26·511	11·343	15·306
	10	17·857	26·530	9·85	4·60	·50	·804	11·50	35·542	15·072	22·393	25·903	20·681	30·728	11·940	17·741
D	20	4·018	6·371	7·90	3·76	·50	·619	8·033	18·775	12·840	20·360	14·091	17·108	27·127	9·877	15·662
	10	8·705	15·112	7·90	3·76	·50	·619	8·033	18·775	13·909	24·147	14·091	18·533	32·173	10·700	18·575
E	10	5·402	8·150	7·07	3·00	·50	·485	5·87	11·615	13·952	21·050	8·963	18·081	27·278	10·439	15·749
	5	11·607	19·520	7·07	3·00	·50	485	5·87	11·615	14 989	25 208	8·963	19·424	32·667	11·214	18·860
F	20	14·700	19·200	12·00	6·00	·625	·875	16·906	63·607	13·864	18·111	46·376	19·018	24·84	10·98	14·34

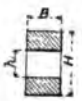
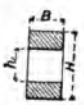
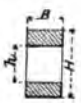
The valuable results of experiments by Mr. W. H. Barlow on the transverse strength of pierced rectangular cross section beams, with varying ratios of area of cross section to circumscribed rectangle, given in Table No. 11, serve well to illustrate the relative tensile breaking stresses on the extreme fibres obtained by the "accepted theory" and the "principle of work" respectively for Section No. 11, and further to give the solution of "The old puzzle about the strength of Beams," for by reference to the column giving the tensile breaking stress in tons per square inch on the extreme fibres determined by "accepted theory," it will be observed that the mean breaking stresses gradually decrease as the ratio of area of cross section of beam to circumscribed rectangle decreases, and that, although the material is the same throughout, the mean tensile breaking stress on the extreme fibres gradually varies from 18·356 tons per square inch for the solid bar, to 11·279 tons per square inch in the beam of maximum girder form. The contrast between these results and the uniform results given by the "principle of work" generally is very striking, and clearly shows that the reason for the many observed discrepancies between the actual strength of beams of various cross section and their calculated strength according to "accepted theory" is due to the neglect of "the principle of work."

Before leaving the subject of transverse strain in relation to symmetrical cross section beams, it is necessary in order to prevent any misunderstanding that the application of the "principle of work" theory to unsymmetrical cross sections should be briefly referred to; for, although it has been advanced and illustrated by experiments given in the preceding tables that the work-coefficient of a symmetrical beam is not altered by merely altering its cross section so long as the section remains symmetrical, yet in the case of materials wherein the elastic or ultimate tensile strength is not equal to the elastic or ultimate crushing strength, the work-coefficient can be increased by making the beam unsymmetrical, and arranging the material above and below the neutral axis so as to take advantage of the difference in the relative work-coefficients of the material under tension and compression, which object has been accomplished in Spencer's Patent Corrugated Spring, shown in Fig. No. 5, Plate 20.

Torsional Strain.

Hitherto we have considered the relative strengths and work-coefficients of materials under tensile and transverse strain, and have endeavoured to show that the "principle of work" accounts for the discrepancies known

LOW.

Form of Section.	Number.	Principle of Work.		
		$= \frac{1}{6}\sqrt{B^2(H^3-h^3)(H-h)}$	Transverse Breaking Stress, Tons per Square Inch on Extreme Fibres.	Tensile Stress in Tons per Square In. $= \frac{\text{Transverse Stress}}{\sqrt{3}}$
	1	·6597	16·890	9·751
	2	·6664	18·931	10·931
	3	·7377	18·917	10·922
	4	·6866	18·686	10·788
Mean	...	...	18·356	10·598
	1	·9584	15·287	8·826
	2	·9483	19·405	11·203
	3	·9082	17·784	10·267
	4	·9077	18·620	10·750
Mean	...	...	17·774	10·261
	1	1·7637	19·173	11·069
	2	1·7768	19·315	11·151
	3	1·7768	18·787	10·847
	4	1·8640	19·417	11·210
Mean	...	...	19·173	11·069
	1	1·2187	16·637	9·605
	2	1·2018	17·964	10·371
	3	1·1921	17·481	10·092
	4	1·1921	16·694	9·638
Mean	...	...	17·194	9·926
	1	1·7606	15·989	9·231
	2	1·7351	16·441	9·492
	3	1·7375	16·202	9·354
	4	1·7680	17·972	10·376
Mean	...	...	16·651	9·613
	1	2·2706	16·766	9·680
	2	2·3592	18·520	10·693
	3	2·2844	17·485	10·095
	4	2·2196	17·573	10·146
Mean	...	...	17·586	10·153
	1	2·1515	16·429	9·485
	2	2·1807	15·737	9·086
	3	2·1004	15·446	8·918
	4	2·1344	16·957	9·790
Mean			16·142	9·319

to exist between their actual behaviour under loads applied and that calculated by the "accepted theory," and we have now to apply the same methods of investigation to the solution of various problems connected with torsional strain.

As previously stated, it was the behaviour of helical springs wherein the material is under torsional strain which suggested these investigations, and although on first thought it may appear to require a stretch of imagination to connect in any way the results of experiments on helical springs with the behaviour of shafting under torsional strain, yet the relationship existing between the two is so marked as to afford the most delicate means of testing the torsional strength and elasticity of materials, capable of being made into a spring; it is therefore intended, first, to show the relationship existing between the strength and elasticity of a helical spring and that of a shaft under torsional strain, and afterwards to show the relative torsional strength and elasticity of shafts of various cross sections from the strength and elasticity of helical springs having corresponding cross sections.

Firstly, then, with regard to the deflection and strength of a helical spring made from a bar of circular cross section.

The deflection of any helical spring is given by the formula—

$$d = \frac{LR^2W}{GI^p} \qquad (1)$$

where d = the deflection with any load (W).
L = the length of the bar uncoiled.
R = the helical radius of the spring.
W = any load applied.
G = the modulus of transverse elasticity of the material.
I^p = the polar moment of inertia of the cross section of the bar.

And further, let

n = the number of free coils.
d_1 = the safe deflection of the spring.
D = the diameter of the bar.
$Z = \frac{\pi}{16} D^3$ = the modulus of section of a round bar to resist torsion ("accepted theory").
W_1 = the safe load.
f_t = the safe limit of torsional stress determined by experiments on circular bars.
Vol. = the volume of material used.

All the dimensions being taken in inches, and loads in pounds.

Then, in the case of a bar of solid circular section—

$$I^p = \frac{\pi}{32} D^4$$

and therefore

$$d = \frac{32\ WR^2L}{\pi\ GD^4} \qquad (2)$$

It is also evident that $L = 2\pi Rn$ very approximately, the approximation being rendered nearer by the fact that the bar stretches slightly while being coiled.

Substituting the value of (L) thus obtained, in formula (2) we obtain—

$$d = \frac{64\ \pi RnR^2W}{G\pi D^4} = \frac{64\ nR^3W}{GD^4}, \qquad (3)$$

which is the formula given by Professor Rankine as representing the deflection of a helical spring made from a bar of circular cross section.

The safe load capable of being carried by the spring is given by the formula—

$$W_1 = \frac{Z_t f_t}{R} = \frac{\pi D^3 f_t}{16\ R}, \qquad (4)$$

and substituting the safe load W_1 in formula (4) for (W) in formula (3), and reducing, we obtain the safe deflection formula, thus:—

$$d_1 = \frac{64\ nR^3\pi D^3 f_t}{16GD^4R} = \frac{4\ \pi nR^2 f_t}{GD}, \qquad (5)$$

and multiplying the safe deflection thus obtained by the safe load, we obtain *twice* the work-coefficient, thus:—

$$\text{Work} \times 2 = \frac{4\ \pi nR^2 f_t}{GD} \times \frac{\pi D^3 f}{16\ R} = \frac{\pi\pi D^2 R f_t^2 n}{4\ G}. \qquad (6)$$

But $2\pi Rn$ = the length of bar of which the spring is made, and therefore formula (6) becomes

$$\text{Work} \times 2 = \tfrac{1}{2}\frac{\pi D^2 L f_t^2}{4\ G}. \qquad (7)$$

But πD^2L = the volume of material in the spring, and therefore

$$\text{Work} \times 2 = \tfrac{1}{2}\frac{\text{Vol. } f_t^2}{G} \qquad (8)$$

and

$$\text{Work} = \tfrac{1}{4}\frac{\text{Vol. } f_t^2}{G} \qquad (9)$$

which gives the amount of work overcome by the spring while being deflected through a given distance by a given load determined as above.

Similarly, let D = the diameter, and L = the length of a solid circular shaft, as in Fig. 6, Plate 20., fixed at one end, and acted upon by a weight (W) at the end of a lever of radius (R).

The deflection or circular distance (= d) moved through by the weight (W) at the point of application is given by the formula—

$$d = \frac{LR^2W}{GI^p} \qquad (10)$$

which, for a solid circular section, becomes—

$$d = \frac{32LR^2W}{\pi\ D^4G}. \qquad (11)$$

The safe load (W_1) capable of being supported at end of radius (R) is—

$$W_1 = \frac{\pi}{16}\frac{D^3f_t}{R}, \qquad (12)$$

and substituting this safe load, W_1, in place of W in formula (11), and reducing, we obtain the safe deflection, thus :—

$$d_1 = \frac{32LR^2\pi D^3f_t}{16\pi GD^4R} = \frac{2LRf_t}{GD} \qquad (13)$$

and multiplying the safe deflection by the safe load, we obtain twice the work-coefficient—

$$\text{Work} \times 2 = \frac{2LRf_t}{GD} \times \frac{\pi D^3f_t}{16\ R} = \tfrac{1}{2}\frac{\pi D^2Lf_t^2}{4\ \ G} \qquad (14)$$

But $\frac{\pi}{4}D^2L$ = the volume of material in the shaft, and therefore

$$\text{Work} \times 2 = \tfrac{1}{2}\frac{\text{Vol.}\ f_t^2}{G} \qquad (15)$$

and

$$\text{Work} = \tfrac{1}{4}\frac{\text{Vol.}\ f_t^2}{G} \qquad (16)$$

giving the torsional work-coefficient of a shaft of solid circular cross section under conditions of load and fixing already specified, being identical with that already obtained for a helical spring—(see formula 9).

But objection might be taken to this method of comparison on the ground that the values of f_t calculated by the formula—

$$f_t = \frac{WR}{Z_t} = \frac{WR}{\frac{\pi}{16}D^3} \qquad (17)$$

from the results of experiments on helical springs made from circular bars might not correspond with the values of f_t obtained from experiments on ordinary torsion test pieces of similar material similarly treated ; and in order to test the validity, or otherwise, of this objection, the following experiment was made :—

A helical spring having the following dimensions :—

Height of spring unloaded = 14″
Helical diameter ... = 5
Diameter of bar ... = 1″
No. of coils ... = 9½

and made from a bar of ordinary rivet steel, was tested by successive

increments of load, the deflections being registered and the loads removed after each addition to ascertain "set."

The first "set" corresponding with the elastic limit was observed with a load of 15 cwts., or $\frac{3}{4}$ of a ton on the spring, giving a value of f_t by formula 17 of—

$$f_t = \frac{\frac{3}{4} \times 2\frac{1}{2}}{0{\cdot}196} = 9{\cdot}56 \text{ tons per square inch.}$$

Now the writer knew from previous experience that the torsional elastic limit of similar steel tested in the ordinary way was reached when the stress on the outer fibres, calculated by formula 17, was equal to from 9 to 10 tons per square inch, thus showing that the results obtained by one method of investigation were identical with those obtained by the other.

Having proved that the work-coefficient of a helical spring is identical with the work-coefficient of a shaft of similar cross section under torsional strain, the next question which suggests itself is,—Can we by altering the cross section of the bar in a helical spring, in any way alter its work-coefficient? And to satisfy the terms imposed by this question, experiments were carefully conducted on several unhardened and untempered helical springs made from the different cross sections of steel, illustrated in Plates 21, 22, and 23, the results of these experiments being recorded in Table No. 12.

In order that the results of these experiments might be strictly comparable throughout, it was absolutely necessary that the material of which the springs were made should be as uniform as possible, and for this purpose the whole of the springs were made from one ingot of mild spring steel, and afterwards tested in the ordinary way by successive increments of load, the deflection due to each increment being registered, and the load removed after each addition to ascertain "set." On the first indication of "set," the springs were considered to have reached their elastic limit, and the work-equivalents in inch pounds per pound weight of spring, given in Table No. 12, are all referred to this limit as a basis of comparison, and a glance at this table is sufficient to show that the work-equivalents of the various springs are the same, since the variation between the mean work-coefficients of different cross section springs is not more than that observed between different springs of similar cross section, and quite within the limits of experimental error and structural irregularities of the material; in other words, weight for weight and work for work, one cross section of helical spring is as good as another, and what is true in the case of a spring is equally true in the case of a shaft of similar cross section.

TABLE No. 12.

EXPERIMENTS CONDUCTED AT THE NEWBURN STEEL WORKS TO ASCERTAIN THE RELATIVE WORK-COEFFICIENTS OF HELICAL SPRINGS MADE FROM BARS OF VARIOUS CROSS SECTION.

Form of Cross Section.	Distinguishing Letter.	Weight of Spring in Pounds.	Elastic Limit.		
			Load on Spring in Pounds.	Total Work Done in Inch Pounds.	Work Equivalent in Inch Pounds per Pound Weight of Spring.
	A	36·25	3675	2905	80·13
	B	35·50	3710	3031·875	85·40
	C	36·00	3763	3006·828	83·49
	D	35·75	3710	3077·812	86·09
	E	36·00	3640	2961	82·25
	F	35·50	3556	2852·325	80·34
	G	34·00	3535	2820·343	83·18
	H	34·50	3500	2821·875	81·79
	I	...	...	...	...
	J	33·50	3214	2703·400	80·69
	K	33·00	3290	2623 340	79·49
	L	32·75	3248	2641·800	80·66
	M	33·00	3360	2555	77·42
	N	33·25	3500	2797·375	84·13
	O	33·25	3570	2851 800	85·76
	P	33·25	3710	2704·625	81·34
	Q	33·50	3735	2742·474	81·86
	R	33·50	3724	2724·610	81·33

NOTE.—Spring (I) was so irregular in its results that it has been neglected.

We are now in a position to compare these experimental results with those given by accepted theoretical formulæ; but, unfortunately, the limits of this paper will not admit of an investigation of the polar moments of inertia and torsional moduli of resistance for elliptical and parallelogram cross sections according to the "principle of work," and we must therefore pass them over (although aware of the fact that their theoretical and actual work-coefficients are widely at variance with each other), and confine ourselves to a consideration of the relative torsional work-coefficients of the circular and square cross sections, illustrated in Table No. 13, and afterwards consider the hollow circular section No. 3. For this purpose, in Fig. 6, Plate 20,

Let d = the deflection or distance moved through by the load (W) at end of lever of radius (R).

L = the length of the shaft.

R = the radius of application of load.

W = any load applied at end of lever.

W_1 = the safe load applied at end of lever.

d_1 = the safe deflection due to load (W_1).

G = the modulus of transverse elasticity of the material.

I_p = the polar moment of inertia of the cross section of the shaft.

Z_t = the torsional modulus of section of the shaft ("accepted theory").

f_t = the safe limit of torsional stress determined by experiments on circular bars.

Vol. = the volume of material used.

All dimensions being taken in inches, and loads in pounds.

Referring to Table No. 13, and comparing the theoretical work-coefficients of round and square bars respectively, it might be inferred from the relationship given that the work-equivalent per unit of weight was less for square than for round cross sections; but it has already been shown by the results of experiments on helical springs that their work-equivalents are identical; and taking the round section as the basis of comparison, the problem which we have to solve is—whether the low value representing the theoretical work-equivalent of a square bar is due to its theoretical deflection formula, or due to its strength formula, or due to both.

Firstly, then, the deflection or circular distance (d) moved through by the weight (W) at its point of application, is given by the formula—

$$d = \frac{LR^2W}{GI^p}. \qquad (18)$$

TABLE No. 13.

TABLE OF TORSIONAL SAFE DEFLECTIONS, MODULI OF RESISTANCE, WORK-COEFFICIENTS, ETC., OF BARS OF VARIOUS CROSS SECTION, ACCORDING TO ACCEPTED THEORY, FIXED AT ONE END, AND ACTED UPON BY A WEIGHT (W) AT THE END OF A LEVER OF RADIUS (R), AS IN FIG. 6 (PLATE 20).

No.	Form of Cross Section	Polar Moment of Inertia I^p.	Modulus of Torsional Resistance $= Z_t$.	Area of Cross Section.	Deflection at Point of Application of Load $= d = \frac{LR^2W}{GI^p}$.	Safe Load at end of Lever $= W_1 = \frac{Z_t f_t}{R}$.	Safe Deflection at Point of Application of Load $= d_1 = \frac{LR^2W_1}{GI^p}$.	Twice the Work-Coefficient.
1	Circle.	$\frac{\pi}{32}D^4$	$\frac{\pi}{16}D^3$	$\frac{\pi}{4}D^2$	$\frac{32}{\pi}\frac{LR^2W}{D^4G}$	$\frac{\pi}{16}\frac{D^3f_t}{R}$	$\frac{2LRf_t}{GD}$	$\frac{1}{2}\frac{\text{Vol.}f_t^2}{G}$
2	Square.	$\frac{1}{6}S^4$	$\frac{1}{3\sqrt{2}}S^3$	S^2	$\frac{6LR^2W}{GS^4}$	$\frac{S^3f_t}{\sqrt{2}R}$	$\frac{2LRf_t}{\sqrt{2}GS}$	$\frac{1}{3}\frac{\text{Vol.}f_t^2}{G}$
3	Hollow Circle.	$\frac{\pi}{32}(D^4-d_a^4)$	$\frac{\pi}{16}\frac{(D^4-d_a^4)}{D}$	$\frac{\pi}{4}(D^2-d_a^2)$	$\frac{32}{\pi}\frac{LR^2W}{(D^4-d_a^4)G}$	$\frac{\pi}{16}\frac{(D^4-d_a^2)f_t}{DR}$	$\frac{2LRf_t}{GD}$	$\frac{1}{2}\frac{\pi}{4}\frac{(D^4-d_a^4)Lf_t^2}{D^2G}$

and according to "accepted theory" $I^p = \frac{S^4}{6}$ for a square section bar; substituting this value in formula 18, we obtain—

$$d = \frac{6LR^2W}{GS^4}. \qquad (19)$$

as representing the twist of a square bar within the elastic limit, while in the case of a circular bar it has been shown that—

$$d = \frac{32LR^2W}{\pi D^4G}. \qquad (20)$$

It is evident that we may transpose these formulæ (19 and 20), and use them to determine the values of (G) in actual experiments on square and round bars, thus :—

$$G = \frac{6WR^2L}{dS^4} \qquad (21)$$

for square sections; and

$$G = \frac{32WR^2L}{\pi dD^4} \qquad (22)$$

for circular sections. And in a series of experiments conducted by Prof. Bauschinger on the torsional strength and stiffness of square and round steel bars from Rechitza, Hungary, the values of (G) were determined from these formulæ, with the result that in every instance the recorded values of (G) were greater for round than for square bars, giving a mean ratio of—

$$\frac{\text{G for square bars}}{\text{G for round bars}} = \cdot 848.$$

This fact being referred to by Professor Bauschinger as follows:—

"Il est remarquable que ce module d' élasticité est toujours plus fort pour les barres rectangulaires que pour les barres rondes ; ce qui permet de conclure que la théorie de la résistance à la torsion n'est exacte même dans les limites de l'élasticité que pour des sections circulaires."

"It is remarkable that this modulus of elasticity is always higher for bars of rectangular section than for round bars ; which permits the conclusion, that the theory of torsional resistance is not exact even within the limits of elasticity, except for circular sections."

Independent of these results however, the relative deflections of helical springs made from round and square bars would indicate a similar conclusion, and point to the fact that the formula expressing the twist of a square bar is in error; because the transverse modulus of elasticity (G) is a property of the material and not dependent upon the shape of the

bar. We may therefore proceed to alter this formula (21) to such an extent that the values of (G) determined from it may compare with those obtained from round bars of similar material.

It is evident on reference to formula (21), that the entire discrepancy here referred to must be due to the polar moment of inertia (I^p), because all the other factors in the equation are experimentally determined; and therefore, in order that (G) for round bars and (G) for square bars may be equal, the polar moment of inertia for square bars must be decreased as follows:—

$$I^p = \frac{S^4}{6} \div 0{\cdot}848 = \frac{S^4}{7{\cdot}07} = \frac{S^4}{5\sqrt{2}},$$

from which we obtain—

$$d = \frac{5\sqrt{2}\,WLR^2}{GS^4} \qquad (23)$$

as representing the torsional deflection or arc of twist for a square bar; and bearing in mind that the work-coefficient of a square bar should equal that of a round bar, then—

$$\text{Work} \times 2 = \tfrac{1}{2}\frac{\text{Vol}\,f_t^2}{G} = \tfrac{1}{2}\frac{S^2 L f_t^2}{G}, \qquad (24)$$

which is obtained by substituting the square of the safe load (W_1) in place of (W) in formula (23), from which it follows that—

$$\frac{5\sqrt{2}\,LR^2}{GS^4} \times W_1^2 = \tfrac{1}{2}\frac{S^2 L f_t^2}{G}; \qquad (25)$$

therefore—

$$W_1^2 = \tfrac{1}{2}\frac{S^2 L f_t^2 GS^4}{G5\sqrt{2}\,LR^2} = \frac{S^6 f_t^2}{10\sqrt{2}R^2} \qquad (26)$$

$$\therefore\ W_1 = \sqrt{\frac{S^6 f_t^2}{10\sqrt{2}\,R^2}} = \frac{1}{\sqrt{10\sqrt{2}}} \times \frac{S^3 f_t}{R}; \qquad (27)$$

but $W_1 = \dfrac{f_t Z_t}{R}$, where (Z_t) = the modulus of torsional resistance; therefore (Z_t) by formula (27) becomes—

$$Z_t = \frac{1}{\sqrt{10\sqrt{2}}} S^3 = {\cdot}2658 \times S^3 \qquad (28)$$

according to the "principle of work," while the value of (Z_t), according to accepted theory, is—

$$Z_t = \frac{1}{3\sqrt{2}} S^3 = {\cdot}2357 \times S^3 \qquad (29)$$

and in order to determine whether the modulus of torsional resistance given by the "principle of work" formula 28 was more in accordance with actual results than the accepted theoretical modulus 29, the following experiments were made on the torsional strength of square and round test-pieces cut from the same bar, the object being to make the elastic stresses

obtained in the case of round bars the basis of comparison to which the elastic stresses for square bars determined by formulæ 28 and 29 respectively could be referred; and by reference to the results of these experiments recorded in Table No. 14, it will be observed that the mean elastic stress of 11·538 tons per square inch obtained by the "principle of work" formula in the case of square bars is almost identical with that of 11·554 tons per square inch obtained for round bars—a result which is to be desired, considering that all the test pieces were cut from one bar; while on the other hand the variation between the *theoretical* elastic stresses of 13·012 and 11·554 tons per square inch respectively for square and round bars, clearly indicates a source of error due to the neglect of the "principle of work."

The Fallacy of the "Accepted Theory" of the Strength of Hollow Shafting.

In applying the methods of investigation hitherto adopted to the solution of the strength and work-equivalent of a hollow shaft under torsional strain, we find the same marked discrepancies between the results indicated by "accepted theory" and those indicated by the "principle of work," and the question naturally aries,—Is the "principle of work" theory true in relation to all other symmetrical cross sections, and not true in the case of hollow shafting? and therefore, in dealing with this subject, let us contrast the results indicated by the two theories, and refer all differences to the test of actual experiment.

Firstly then, in the case of a hollow circular shaft, fixed at one end and acted upon by a weight (W) at the end of a lever of radius (R), as in Fig. 6, Plate 20.

Let D = the outside diameter of the shaft in inches.

d_a = the diameter of hole through shaft in inches.

$I^p = \frac{\pi}{32}(D_4 - d_a^4)$ = the polar moment of inertia of the cross section of the shaft.

then the deflection or arc of twist moved through by the weight (W) at its point of application, is given by the formula—

$$d = \frac{L\ R^2\ W}{G\ I^p} \qquad (30)$$

which for a hollow circular section becomes—

$$d = \frac{32\ \ L\ R^2\ W}{\pi\ (D^4 - d_a^4)\ G'} \qquad (31)$$

and here it is necessary to remark that both the actual and theoretical deflection are in accord.

TABLE No. 14.

TABLE OF RESULTS OF EXPERIMENTS MADE AT THE NEWBURN STEEL WORKS ON THE TORSIONAL STRENGTH OF SQUARE AND ROUND TEST PIECES, CUT FROM THE SAME BAR AS THOSE GIVEN IN TABLES NOS. 2, 3, AND 4.

Number.	Size of Test Pieces.	Load in Lbs. on End of 12 inch Lever.		Accepted Theory.			Principle of Work.		
		Elastic Limit.	Maximum Load.	Modulus of Section Z_t.	Torsional Stress in Tons per Square Inch.		Modulus of Section Z_t.	Torsional Stress in Tons per Square Inch.	
					Elastic Limit.	Maximum Stress.		Elastic Limit.	Maximum Stress.
Q198	1 inch square	572·500	1746·125	·2357	13·012	39·687	·2658	11·538	35·192
Q199	„	572·500	1774·75	·2357	13 012	40·335	·2658	11·538	35·769
Q200	„	572·500	1746·125	·2357	13·012	39·687	·2658	11·538	35·192
Mean	...	...	...	...	13·012	39·903	...	11·538	35·384
Q201	1 inch diameter	429·375	1173·625	·19635	11·669	32·020	·19635	11·669	32·020
Q202	„	429·375	1173·625	·19635	11·669	32·020	·19635	11·669	32·020
Q203	„	415·062	1187·937	·19635	11·324	32·411	·19635	11·324	32·411
Mean	...	...	...	...	11·554	32·150	...	11·554	32·150

Substituting the theoretical safe load—

$$W_1 = \frac{\pi}{16}\frac{(D^4 - d_a^4) f_t}{D\,R}$$

in place of (W) in formula (31), we obtain the theoretical safe deflection thus:—

$$d_1 = \frac{32\,L\,R^2\,\pi\,(D^4 - d_a{}^4)\,f_t}{16\;\pi\,(D^4 - d_a^4)\,G\,D\,R} = \frac{2\,L\,R f_t}{G\,D}, \qquad (32)$$

and multiplying this safe deflection by the theoretical safe load, we obtain *twice* the theoretical work-equivalent, thus :—

$$\text{Work} \times 2 = \frac{2\,L\,R f_t}{G\,D} \times \frac{\pi\,(D^4 - d_a{}^4) f_t}{16 \qquad D\,R} = \tfrac{1}{2}\frac{\pi\,(D^4 - d_a{}^4)\,L\,f_t{}^2}{4 \qquad D^2\,G} \qquad (33)$$

But here it will be observed that the theoretical work-equivalent of the shaft is not represented in terms of material used, being similar in this respect to Sections 5—11, Table No. 1, already considered under transverse strain ; and acting on the assumption that the "principle of work" is equally applicable in the case of a hollow shaft as in all the other cases previously considered, we may proceed to determine the safe load (W_1) and modulus of torsional resistance (Z_t) by the method adopted in the preceding investigations, making the solid circular section the basis of comparison.

In order then that twice the work-coefficient of the hollow shaft might be proportional to the volume of material used, and represented by the formula—

$$\text{Work} \times 2 = \tfrac{1}{2}\,\frac{\text{Vol.}\,f_t{}^2}{G}$$

already obtained in the case of the solid circular shaft, it is evident that formula (33) should have been—

$$\text{Work} \times 2 = \tfrac{1}{2}\frac{\pi\,(D^2 - d_a{}^2)\,L f_t{}^2}{4 \qquad G} = \tfrac{1}{2}\,\frac{\text{Vol.}\,f_t{}^2}{G},$$

and bearing in mind that twice the work-coefficient is obtained by substituting the square of the safe load (W_1) in place of (W) in formula (31), it follows that—

$$\frac{32 \quad L\,R^2}{\pi\,(D^4 - d_a{}^4)\,G} \times W_1{}^2 = \tfrac{1}{2}\frac{\pi\,(D^2 - d_a{}^2)\,L\,f_t{}^2}{4 \qquad G} \qquad (34)$$

$$\therefore W_1{}^2 = \frac{\pi^2 f_t{}^2\,(D^2 - d_a{}^2)\,(D^4 - d_a{}^4)}{256\;R^2}$$

$$\therefore W_1 = \sqrt{\frac{\pi^2 f_t{}^2\,(D^2 - d_a{}^2)\,(D^4 - d_a{}^4)}{256\;R^2}} = \frac{\pi f_t}{16\;R}\,\sqrt{(D^2 - d_a{}^2)\,(D^4 - d_a{}^4)}$$

But— (35)

$$\frac{\pi f_t}{16\,R}\sqrt{(D^2-d_a{}^2)(D^4-d_a{}^4)}=\frac{\pi f_t}{16\,R}\sqrt{(D^2-d_a{}^2)(D^2-d_a{}^2)(D^2+d_a{}^2)}$$

$$\therefore W_1=\frac{\pi f_t}{16\,R}(D^2-d_a{}^2)\sqrt{D^2+d_a{}^2} \qquad (36)$$

But $W_1=\frac{f_t Z_t}{R}$ where (Z_t) = the modulus of torsional resistance; and therefore (Z_t) by formula (36) becomes—

$$Z_t=\frac{\pi}{16}(D^2-d_a{}^2)\sqrt{D^2\times d_a{}^2} \qquad (37)$$

in order to comply with the "principle of work," while according to the accepted theory—

$$Z_t=\frac{\pi}{16}\frac{(D^4-d_a{}^4)}{D} \qquad (38)$$

the difference between the results obtained by the respective formulæ (37 and 38) being considerable.

The writer had proceeded thus far with his investigations, being able to compare the results indicated by the "principle of work" with actual published experiments; but here a difficulty arose, in the fact that there were no published results of experiments on the torsional strength of hollow shafting to which reference could be made. At this juncture the writer mentioned the subject to J. W. Spencer, Esq., of Messrs. John Spencer and Sons, Newburn Steel Works, who instructed him to have the necessary test-pieces and experiments made to elucidate the question at issue. The detail results of these experiments are recorded in Table No. 15 and illustrated by the Diagrams in Plate 24, wherein the radial distances from the focus (O) to outside of diagrams represent the tons per square inch for any given angle of twist, the dotted line diagrams being calculated by the *theoretical* formula, and the full line diagrams by the "principle of work;" and attention is called to the gradual reduction in the radial distances to the dotted line curve, as the diameter of hole in test-piece increases, although the material in all cases was the same.

Description and Preparation of the Test-Pieces.—It was necessary, in order that the results of these experiments might be uniform and comparable, that the material from which the test-pieces were prepared should be free from structural irregularities. A piece of steel of known uniform quality was therefore taken, and after being "cogged" down under a steam hammer, was rolled to $1\frac{1}{2}$ inches square, and afterwards accurately machined to the dimensions given, viz.:—

3 pieces, 1·125 inches outside diameter, solid.

3	„	1·125	„	„	„	and ·500	inches	diameter	of hole.
3	„	1·125	„	„	„	„ ·625	„	„	
3	„	1·125	„	„	„	„ ·75	„	„	
3	„	1·125	„	„	„	„ ·875	„	„	

The whole of the test-pieces being cut from one long bar.

In Table No. 15, the elastic and ultimate stresses have been calculated by the accepted theoretical and "principle of work" formulæ respectively, the results being arranged side by side for comparison, and it will be observed that although the material is the same throughout, yet, according to "accepted theory," the mean elastic and ultimate stresses gradually decrease from 12·615 and 31·539 tons per square inch respectively in the case of the solid bar, to 9·948 and 25·087 tons per square inch in the case of the hollow test-pieces, with maximum diameter of hole; while on the other hand, both the elastic and ultimate stresses given by the "principle of work" are practically uniform throughout, thus clearly demonstrating the truth of the "principle of work" theory in relation to the torsional strength of hollow shafting.

Having shown by reference to actual experiment that the torsional strength of a hollow shaft is in accordance with that indicated by the "principle of work," we are now in a position to compare the relative torsional strength of hollow shafts with various ratios of internal to external diameter, as given by the "accepted theory" and "principle of work" respectively, and for this purpose Table No. 16 has been calculated, giving the moduli of torsional resistance, etc., of a 20 inch diameter shaft with varying diameters of hole.

Column 3 gives the percentage ratio of inside to outside diameter, and columns 4 and 6 the moduli of torsional resistance determined by "accepted theory" and "principle of work" respectively; column 5 the ratio of strength of hollow to strength of solid shaft according to theory, and column 7 according to "principle of work;" column 8 gives the ratio of strength as per "principle of work" to strength as per theory, and column 9 the percentage error in using the accepted formula.

For example, take the case of a hollow shaft wherein the hole is 55 per cent. of the outside diameter, then, according to "accepted theory," its strength is 90·84 per cent. of that of the solid shaft, but according to the "principle of work," only 79·6 per cent.; in other words, its actual strength is only 87·62 per cent. of that given by theory, and an error is made in using the accepted rule amounting to 14·127 per cent.

TABLE 7.—Test Pieces Cut from One Bar.

Mark of Test.	Dimensions		Principle of Work.	
	External Diam. = D	$Z_t = \frac{\pi}{16}\frac{(D^2 - d_s^2)}{D}\sqrt{D^2 + d_s^2}$	Elastic Limit in Tons per Square Inch.	Maximum Stress in Tons per Square Inch.
Q167	1·125	·279568	12·615	31·539
Q168	1·125	·279568	12·615	32·083
Q169	1·125	·279568	12·615	30·991
Mean		...	12·615	31·539
Q170	1·125	·245504	12·804	31·858
Q171	1·125	·245504	12·804	32·480
Q172	1·125	·245504	12·804	32·792
Mean		...	12·804	32·376
Q173	1·125	·221106	12·830	32·943
Q174	1·125	·221106	12·830	31·209
Q175	1·125	·221106	12·830	32·250
Mean		...	12·830	32·134
Q176	1·125	·186666	12·322	31·628
Q177	1·125	·186666	12·322	31·217
Q178	1·125	·186666	12·322	31·628
Mean		...	12·322	31·491
Q179	1·125	·189921	12·603	31·771
Q180	1·128 ?	...	13·151	33·975
Q181	1·125	·189921	12·603	31·771
Mean of Q179 and Q1		...	12·603	31·771

NOTE.—The hole is with the same modulus Z_t as in Q179 and Q181.

[To face page 114.

TABLE No. 16.

TABLE OF COMPARATIVE TORSIONAL STRENGTHS OF A 20 INCH DIAMETER SHAFT WITH VARYING DIAMETERS OF HOLE, ACCORDING TO ACCEPTED THEORY AND THE PRINCIPLE OF WORK.

Outside Diameter of Shaft = D.	Diameter of Hole = d_a.	$100 \times \frac{\text{Inside Diameter.}}{\text{Outside Diameter.}}$	Accepted Theory. $Z_t = \frac{\pi}{16}\frac{(D^4-d_a^4)}{D}$.	Accepted Theory. $\frac{(D^4-d_a^4)}{D^4} = \frac{Z_t \text{ for Hollow.}}{Z_t \text{ for Solid}}$.	Principle of Work. $Z_t = \frac{\pi}{16}(D^2-d_a^2)\sqrt{D^2+d_a^2}$.	Principle of Work. $\frac{(D^2-d_a^2)\sqrt{D^2+d_a^2}}{D^3} = \frac{Z_t \text{ for Hollow}}{Z_t \text{ for Solid}}$.	Percentage Ratios. $\frac{D \times 100}{\sqrt{D^2+d_a^2}} = \frac{\frac{\pi}{16}(D^2-d_a^2)\sqrt{D^2+d_a^2} \times 100}{\frac{\pi}{16}(D^4-d_a^4)\frac{1}{D}}$	Percentage Ratios. $\frac{100\sqrt{D^2+d_a^2}}{D} - 100 = \left(\frac{\frac{\pi}{16}(D^4-d_a^4)\frac{1}{D} \times 100}{\frac{\pi}{16}(D^2-d_a^2)\sqrt{D^2+d_a^2}}\right) - 100$.
Inches.	Inches.							
20	0	0	1570·800	1·0000	1570·800	1·0000	100	·000
20	1	5	1570·790	·9999	1568·830	·9987	99·87	·124
20	2	10	1570·642	·9999	1562·848	·9949	99·50	·498
20	3	15	1570·004	·9994	1552·634	·9884	98·89	1·118
20	4	20	1568·286	·9984	1537·831	·9790	98·05	1·980
20	5	25	1564·664	·9960	1517·947	·9663	97·01	3·077
20	6	30	1558·076	·9919	1492·366	·9500	95·78	4·403
20	7	35	1547·228	·9849	1460·364	·9296	94·38	5·948
20	8	40	1530·587	·9744	1421·114	·9047	92·84	7·703
20	9	45	1506·387	·9589	1373·707	·8745	91·19	9·658
20	10	50	1472·625	·9375	1317·155	·8385	89·44	11·803
20	11	55	1427·061	·9084	1250·414	·7960	87·62	14·127
20	12	60	1367·224	·8704	1172·385	·7463	85·74	16·619
20	13	65	1290·402	·8214	1081·929	·6887	83·84	19·268
20	14	70	1193·650	·7599	977·876	·6225	81·92	22·065
20	15	75	1073·789	·6835	859·031	·5468	80·00	25·000
20	16	80	927·400	·5904	724·177	·4610	78·08	28·062
20	17	85	750·832	·4779	572·088	·3642	76·19	31·244
20	18	90	540·198	·3439	401·526	·2556	74·32	34·536
20	19	95	291·373	·1854	211·245	·1344	72·50	37·931
20	20	100	...	...	...	...	70·71	41·421
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

In conclusion, the writer begs to acknowledge his deep sense of indebtedness, firstly, to J. W. Spencer, Esq., for his kindly interest and assistance, and for providing the numerous test-pieces from which the results recorded in the preceding tables have been determined in illustration of the "principle of work" theory; and, secondly, to the writer's brother, Frank, for having kindly checked the lengthy numerical calculations involved in the preceding investigations.

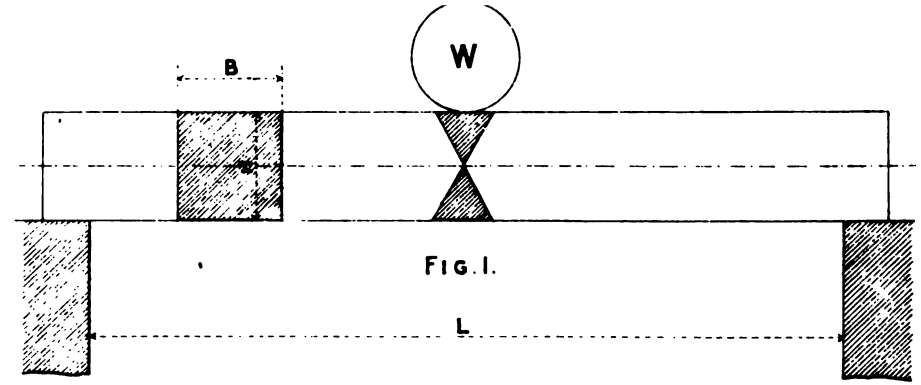


FIG. 1.

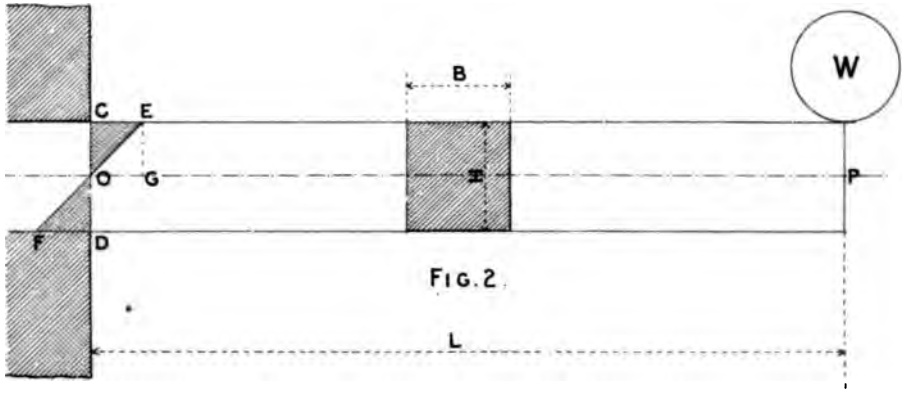
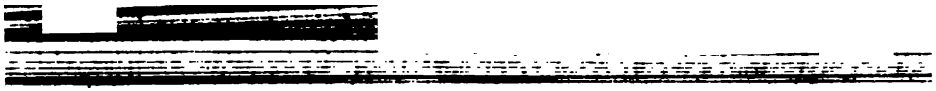
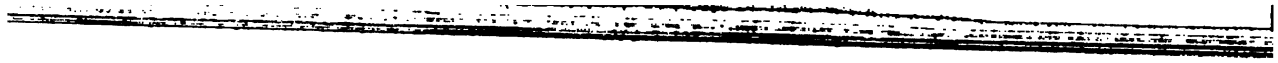
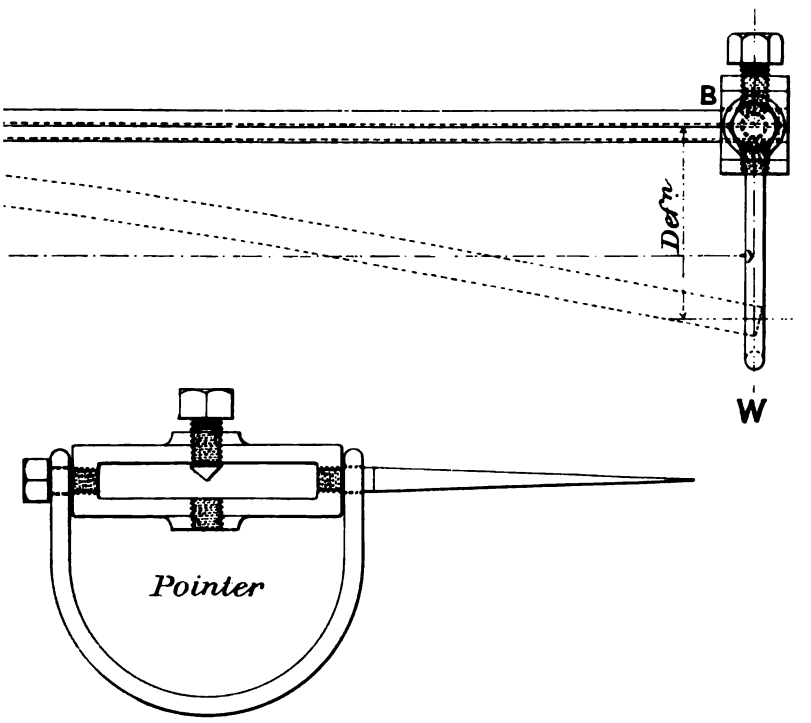


FIG. 2.





"Work" in relation to the Strength of Structures."



4 = 8·521
5 = 9·376
6 = 7·322
Mean = 8·406

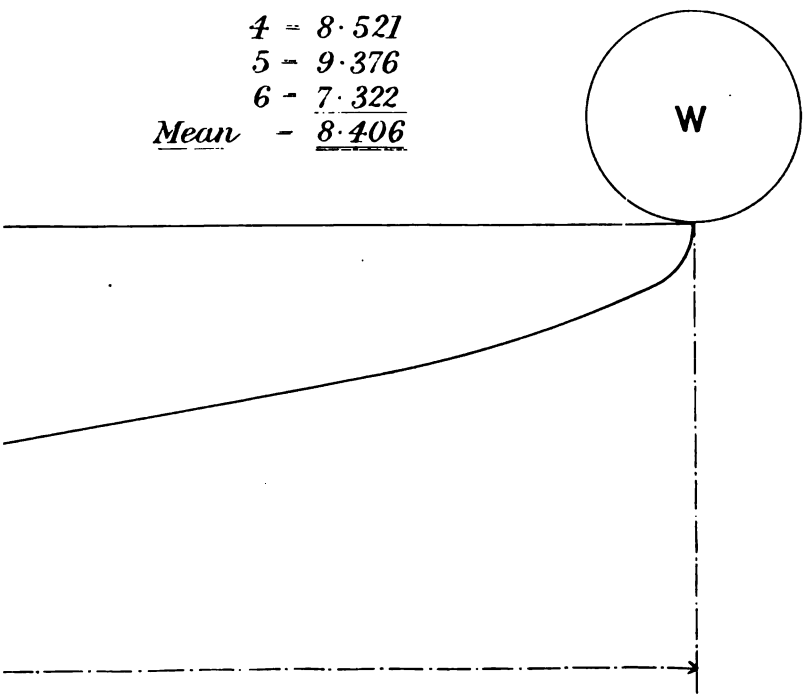
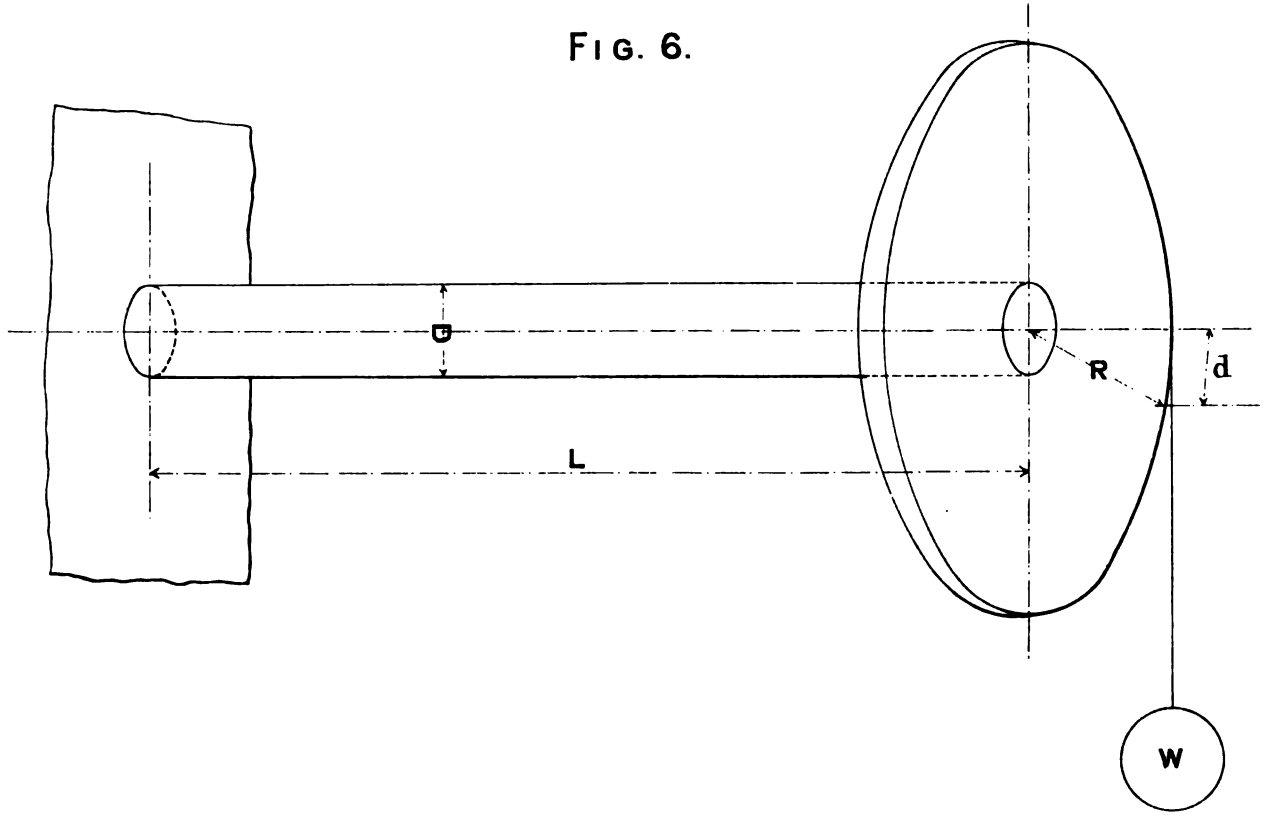
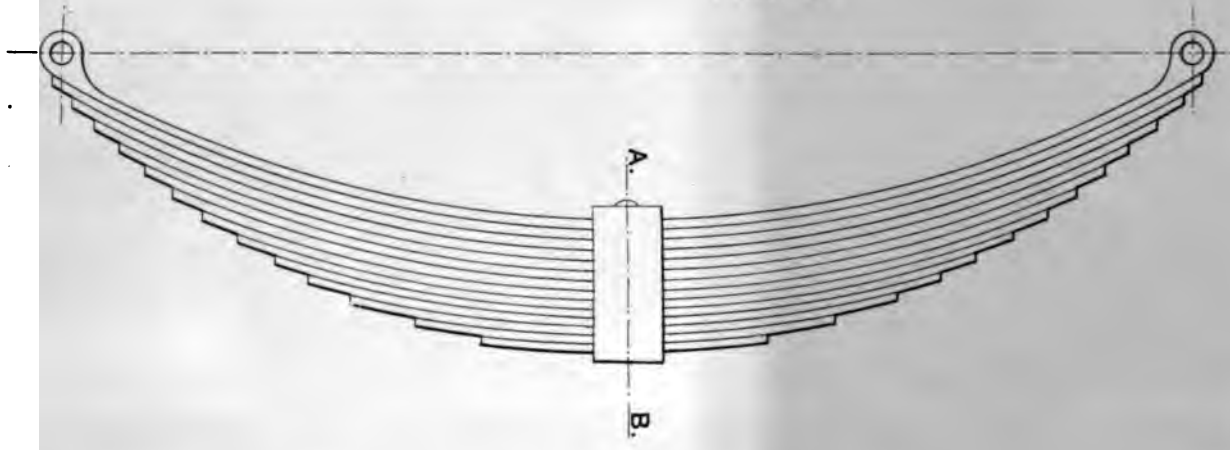


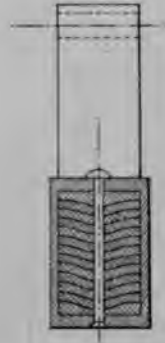
FIG. 6.



To illustrate Mr. Henry Foster's paper on "The Principle of Work in relation to the Strength of Structu

FIG. 5.



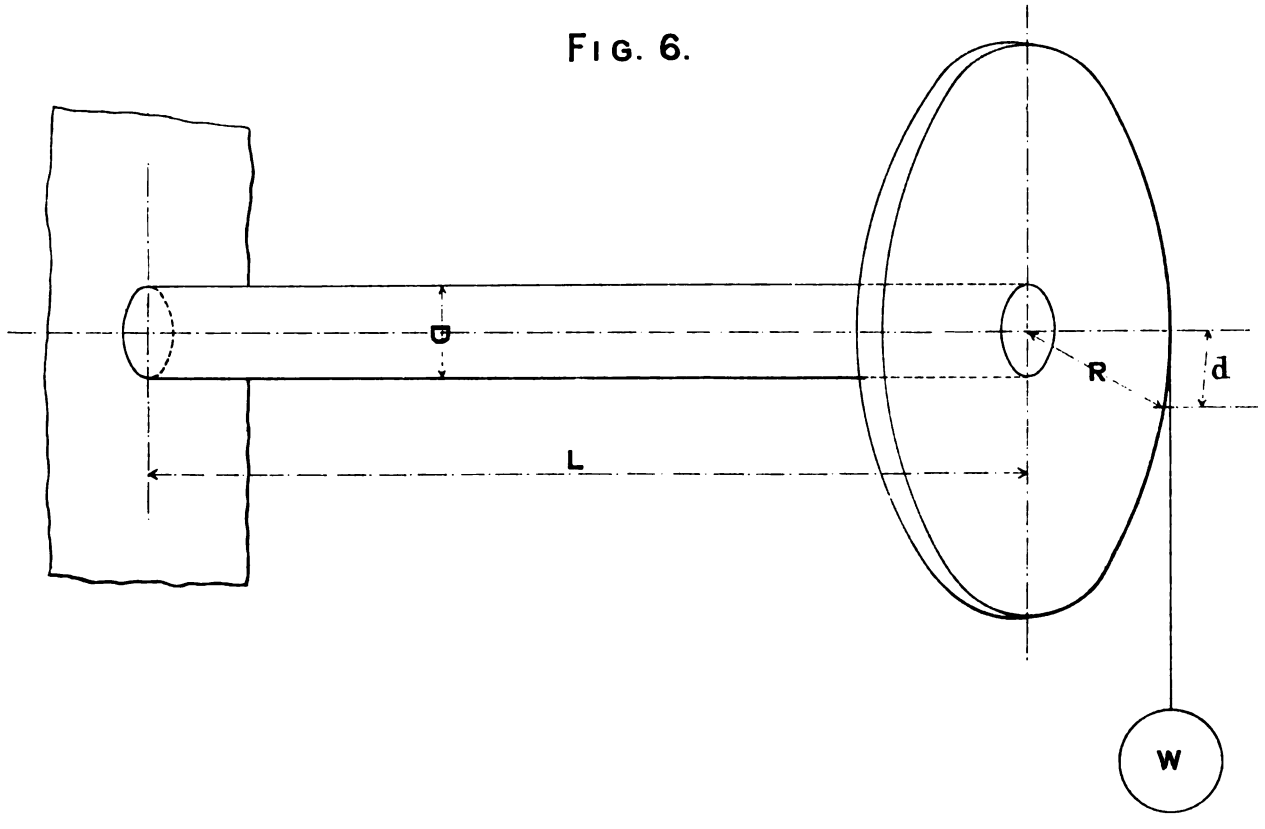


SECTION THRO'. A.B.

CROSS SECTION OF SPRING PLATE
FULL SIZE.

SPENCER'S PATENT CORRUGATED SPRING

FIG. 6.



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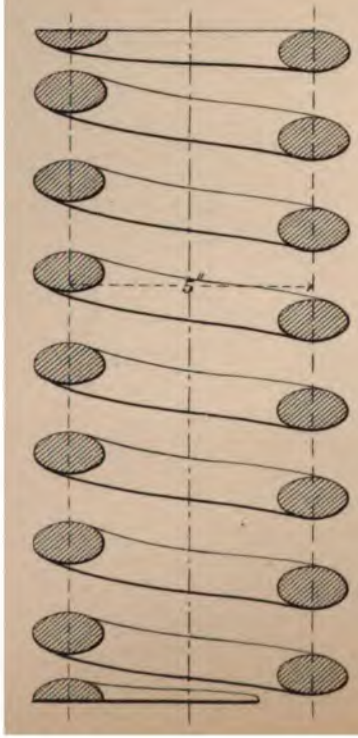
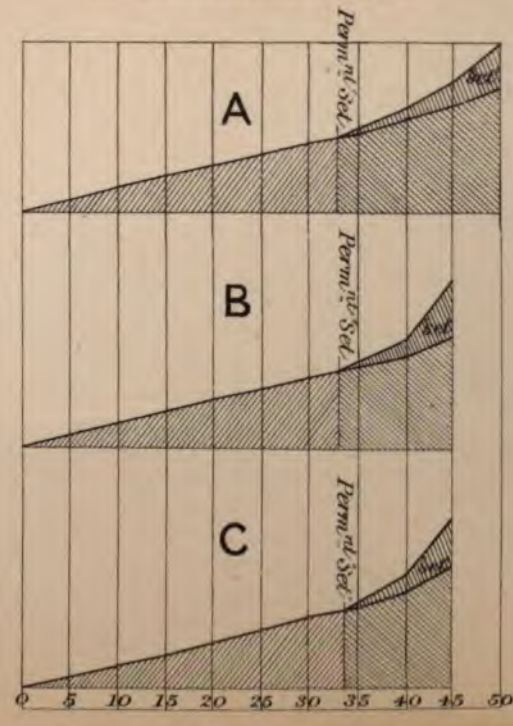
e Mr. Henry Foster's paper on "'The Principle of Work' in relation to the Strength of Structures."

TEST DIAGRAMS.





SECTIONS OF STEEL.

DEFLECTIONS IN INCHES.

DEFLECTIONS IN INCHES.

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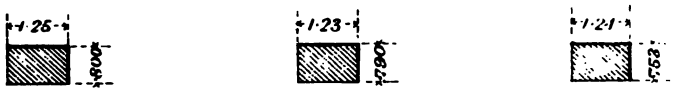

DEFLECTIONS IN INCHES.

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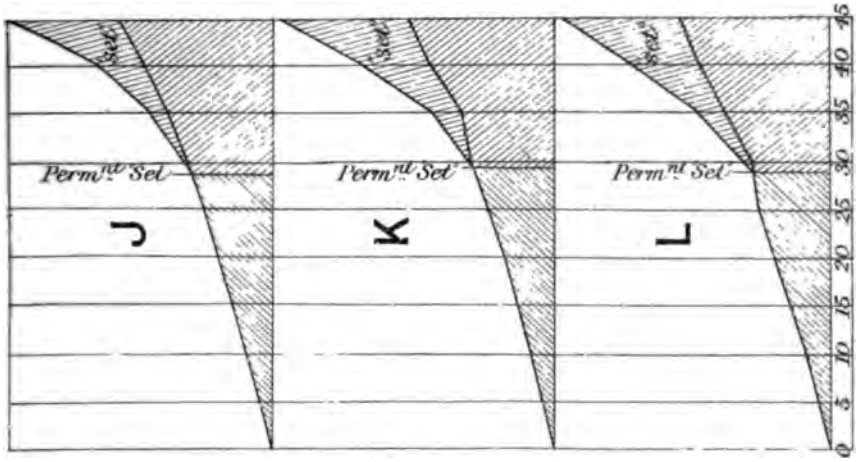

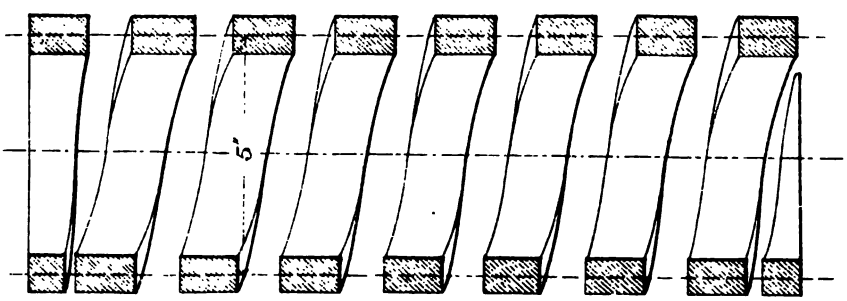

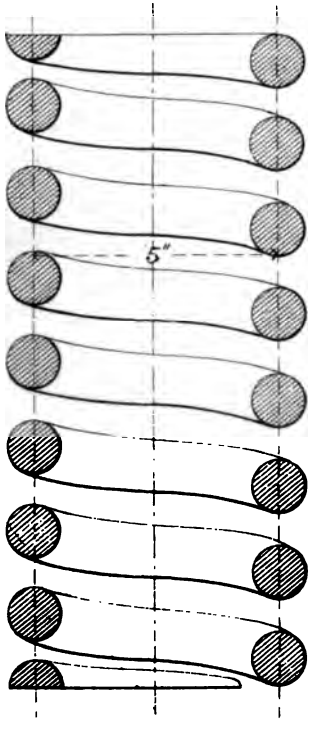
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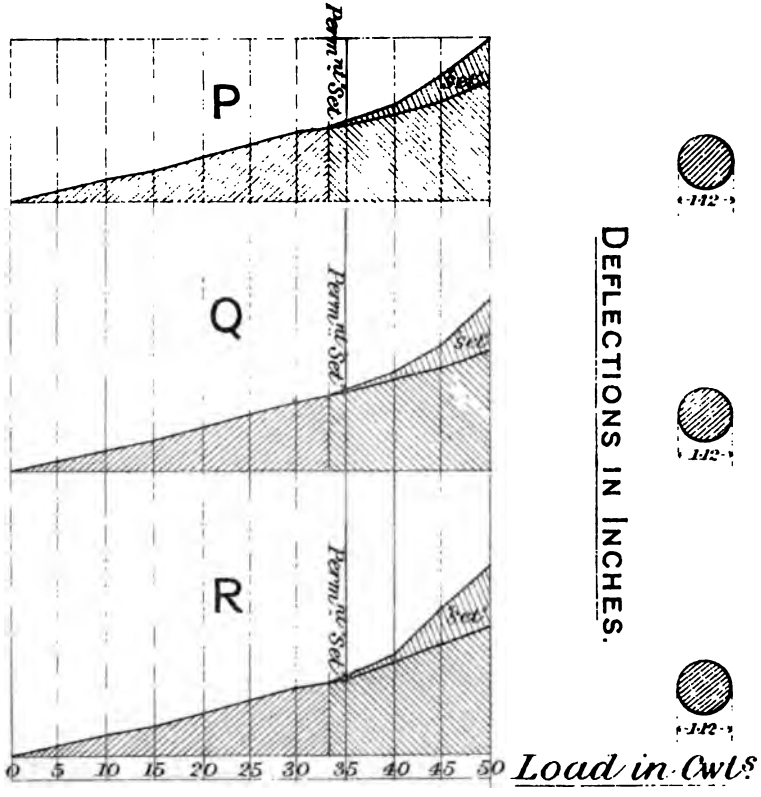
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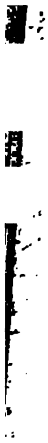
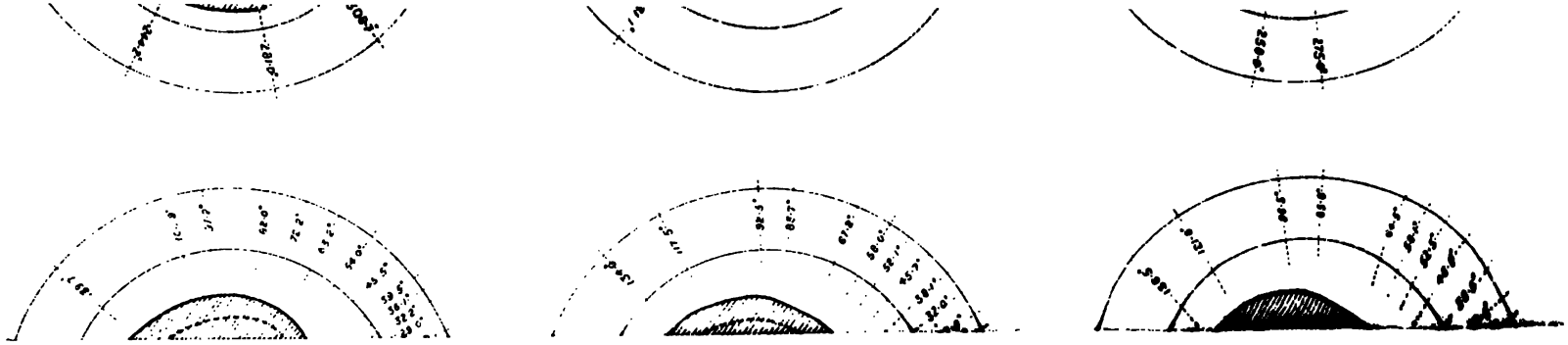




Scale $\frac{1}{10}$ of an Inch Radial Distance from Focus = 1 Ton per Square Inch.

The dotted curve being calculated by the accepted Theoretical formula – $f_t = \frac{16 \cdot D \cdot W \cdot R}{\pi (D^4 - d_a^4)}$

And the full-line curve by the 'Principle of Work' formula $f_t = \frac{16 \cdot W \cdot R}{\pi (D^2 d_a^2)(D^2 + d_a^2)}$

Where f_t = *The torsional stress in tons per □" on outer fibres*

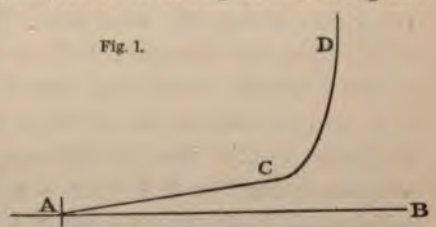
W = *The load in tons on end of lever of Radius (R) in inches*

D = *External dia. of test piece in inches*

d_a = *Internal.* " " " " "

Mr. J. C. SPENCE said, on first reading the paper he was very forcibly impressed with the close agreement between the results of experiment and those calculated by Mr. Foster's method, and equally so by the great discrepancies between experiment and results calculated by the old "accepted method." On further study he came to the paradoxical conclusion, that this agreement with experiment was proof positive that Mr. Foster's theory can not be the true law, or at least not the complete law of the subject, and conversely that the disagreement between the old theory and experimental results is a strong argument in favour of the "accepted theory." The idea which he was about to explain only occurred to him a day or two ago when studying the paper. He must therefore ask their favourable consideration for any crudeness in his statement of it. On the first page (77) of this paper Mr. Foster uses the expression, "so long as the elastic limit of the material is not exceeded, the elongation, deflection, and arc of twist respectively are directly proportional to the loads applied," yet in the body of the paper he entirely ignores the fact that the modulus of elasticity is only a constant between the limits therein named. (It should be said, that in doing so Mr. Foster is in very good company, as every other author does the same.) This fact is however of great importance, attention to it solves at once the old "puzzle about the strength of beams," which has puzzled a generation of able engineers and mathematicians, while the solution stares them in the face in the most elementary experiment on strength of materials, namely, the breaking of a specimen of iron by tensile strain. Consider what happens when a specimen of iron or steel is broken by a direct pull in a testing machine, the load being applied gradually. At first the specimen elongates slowly and uniformly till the strain reaches the elastic limit of the material. After that it begins to elongate much more rapidly till the last ton will probably stretch it more than the first 20 tons. If a strain diagram of this process be made, it will form a figure something like the following sketch (Fig. 1). Where lengths along the line A B represent the weights and heights above A B represent the corresponding extension of the bar. Then as the extension varies uniformly with the strain while that is below the elastic limits, a straight line such as A, C, will be the strain diagram up to the limit, but beyond this point the extension increases at a much faster rate than the strain, so that the

Fig. 1.



strain diagram will no longer be a straight line, but a broken line or curve, such as C D, increasing in steepness till at the point of rupture it goes off to infinity, perpendicular to A B. Next consider the strain diagram of that half of a beam which is in tension when the beam is loaded to its breaking strain (Fig. 2). O A is the neutral axis of beam,

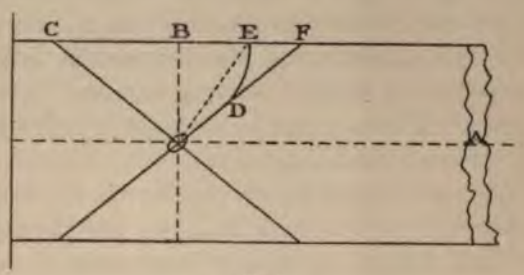


Fig. 2.

B F is the top of beam. When a beam is bent under a load the amount of extension in any layer of the beam will vary directly as the distance of that layer from the neutral axis, and the triangle C B O, will represent accurately the rate of extension in each layer; also for any strain *below* the elastic limit. Extension and strain are in direct proportion, so that for any such strain a straight line such as C O, would be a correct diagram of the strains on each layer. But when the strain exceeds the elastic limit the diagram will no longer be a straight line, but a curve as in Fig. 1. Thus from O to D, when the strain is below the elastic limit, it will be a straight line, from D to E a curve, gradually becoming steeper till at the point of rupture it is vertical. If this is a correct view of the subject, and (although the form of curve does not pretend to be accurate, and would probably vary for different materials) no one can look at a bar being broken in testing without seeing that this is approximately correct; the truth and the error of Mr. Foster's new theory and of the old established theory will be evident. The error common to both is that they assume the triangle C B O, as the strain diagram, not only for strains below the elastic limit but for all strains. (Continue the line O D, till it cuts the top line of beam in F; also join the points E and O, by the line O E.) Now the old theory assumes (wrongly) that the strain diagram is the line O F (that is a continuation of the straight line which would be the true diagram of strains below elastic limit), and that therefore the strain on the top layer is represented by the length B F. While it is now seen that the strain on the top layer is not B, F, but B E, and this is the full solution of the old puzzle about beams. The

puzzle was how to account for the fact that the apparent strength of the top layers of a beam was greatly in excess of the real strength of the material otherwise determined. The mistake was in supposing that, the strain varied directly as the extension, for strains beyond elastic limit. On the other hand Mr. Foster's theory also assumes that the strain diagram is a triangle, and his formulæ give ultimate strength of beams which agree with experiment, so that his strain diagram for the beam at point of rupture must be the line O E. Now this coincides with the assumed true strain curve O D E, only at the extreme points O and E, that is at breaking strains, and at no strain, so that even if Mr. Foster's theory gives reliable results for breaking strength it is not so reliable (for safe working strains) as the old formula, which at strains below elastic limit coincides with the true strain diagram. It will now be self-evident why the speaker thinks agreement with experiment an argument against Mr. Foster's theory, and disagreement with experiment an argument in favour of the old theory. They both start from the wrong basis that the modulus of elasticity is a constant, and, if rightly reasoned, should come to wrong conclusions, the old theory does so—hence the beam puzzle. Mr. Foster's theory agrees with experiment, therefore, though he (Mr. Spence) has not detected the flaw in his reasoning, he was confident there is such a flaw, and would venture to prophesy, that if instead of making his experiments with materials of uniform character (for the purpose he had in view he was compelled to do so) he used materials of very different character, he would find his experiments varying considerably from his calculations. By the theory thus roughly outlined, it can be seen at once why solid rectangular beams should show greater disagreement with the old calculations than girders and other hollow sections. Thus, when the top layer of a beam of rectangular section is strained beyond its elastic limit, the extra stretching of this layer does not increase the strain on it to a proportionate extent, and the beam will not rupture until a very large part of the solid section of the beam is strained to breaking point. But in a girder of I section, when the top flange is strained to its breaking point, the beam will break, as the support it gets from the web will add but very little to its strength. Mr. Foster's formulæ, based on weight of material, will probably be more accurate for breaking strains than other formulæ based on distribution of material, without being more reliable for working strains. The foregoing arguments show that agreement with experiment at breaking strains is an argument against agreement under

working strains; and this will hold for shafts as for beams, unless the modulus of elasticity in torsion is a constant (which is highly improbable) for all strains above as well as below the elastic limit. Mr. Foster certainly deserved their thanks for his most able and most suggestive paper, for whether the Institution was disposed to agree to Mr. Foster's new theory, or to retain the old, or accept of the suggestions laid down by himself (Mr. Spence), it must be conceded that very much knowledge is gained from a searching examination and appeal to experiment in the endeavour to establish the accuracy of fundamental theories.

Professor GARNETT, of the College of Physical Science, Newcastle-upon-Tyne, much regretted that the short time which he had been able to give to Mr. Foster's paper had not allowed him to do it justice, as it must have involved an enormous amount of labour, and could not fail to be a valuable contribution to our knowledge of the elastic properties of steel. Mr. Foster was not, however, justified in his condemnation of "the accepted theory" on the strength of his experimental results, for that theory was intended to apply only so long as no portion of the body was strained beyond its elastic limit, that is, in the case of bending, only so long as Hooke's law strictly applies to every portion of the body. He would therefore confine himself to three points, and attempt to show—

1.—That the "principle of work," when properly applied to transverse strains is consistent with the "accepted theory" so long as no portion of the specimen is strained beyond its elastic limits (and it is only within these limits that the "accepted theory" pretends to be applicable).

2.—That the behaviour of iron and mild steel in the testing machine when exposed to direct tension completely explains the apparently high limit of elasticity when a bar is subjected to bending stress just beyond its limits of perfect elasticity.

3.—That the excessive torsional strength of hollow shafting may be accounted for in precisely the same way as the corresponding characteristic in the transverse strength of beams.

1.—The author of the paper under discussion correctly obtains the expression—

$$\frac{1}{2}\frac{\text{Volume} \times f^2}{E}$$

for the work absorbed by a bar subject to direct tension, provided that the limit of elasticity be not exceeded. As soon as this limit is passed

this formula is very far from true. The discrepancy which the author professes to have found between the results obtained from the "principle of work" and those given by the "accepted theory," as far as transverse strains are concerned, rests wholly on the investigation on pages 83-86, and the method by which formula 3, on page 83, is deduced is fallacious. Referring to Fig. 3, and considering the section D O C, both the extension and the tension of the fibres from O to C vary as the distance of the fibre above O. But the work done in stretching a fibre under the elastic law is one-half the product of the tension and extension, and therefore varies as the square of either. Hence the summation of the elements of work done in stretching the several fibres from O to C in a transverse section of given small thickness, measured along the length of the beam, is the summation of a series of quantities, each proportional to *the square of the distance* of the corresponding fibre from O, and is identical with the determination of the volume of a cone by summing up the several thin slices perpendicular to the axis. Now the volume of a cone is one-third of the height multiplied by the area of the base, and so for the work done in the extension we have—

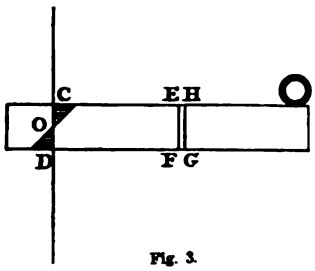


Fig. 3.

$$\text{Work} \times 2 = \frac{1}{3} \frac{\text{Volume} \times f^2}{\text{E}}$$

$$\text{or,} \quad \text{Work} = \frac{1}{6} \frac{\text{Volume} \times f^2}{\text{E}}$$

And a similar result obtains for the fibres subject to compression, so that for the whole thin slice we have—

$$\text{Work} = \frac{1}{6} \frac{\text{Volume} \times f^2}{\text{E}}$$

The coefficient being $\frac{1}{6}$ instead of $\frac{1}{4}$, as given in the paper, and the work being one-third of that corresponding to direct and uniform tension. If we now consider the whole length of a beam of uniform section loaded at the end, which is worked out in accordance with the "accepted theory," on pages 84 and 85 of the paper, we observe that, dividing the beam into equal transverse slices, similar to E F G H, the tension in the top, or any, the same, fibre of any section is proportional to the distance of the section from the loaded end. Hence the work done in stretching that fibre within the thickness of the section is proportional to the square of the same distance. The summation of the work absorbed by the

several sections is therefore the cone problem over again, and since the work absorbed by the last section, corresponding to the base of the cone, is—

$$\frac{1}{6}\frac{\text{Volume of section} \times f^2}{E}$$

it follows that the work absorbed by the whole beam is—

$$\frac{1}{18}\frac{\text{Volume of beam} \times f^2}{E}$$

which agrees with equation 8 on page 85, the result of the "accepted theory." Again, in the parabolic beam of uniform strength the tension of the top fibre of each section is equal to the elastic limit, and the work done on each section is, therefore, proportional to its volume, every section being strained like the last, and the work absorbed by the whole beam is—

$$\frac{1}{6}\frac{\text{Volume} \times f^2}{E}.$$

But we have seen that in a uniform beam the work absorbed is—

$$\frac{1}{18}\frac{\text{Volume} \times f^2}{E}$$

(while the volume of the uniform beam is one-and-a-half times that of the parabolic beam of the same strength). Hence the work done on the uniform beam is one-third that done on the parabolic beam of the same volume when bent to the limit of elasticity. We cannot, therefore, assume, as on page 86, that with a beam of uniform depth the work done is *two-thirds* of that which would be done in a parabolic beam of the same *volume*, for it is only *one-third* of that amount while it is only one-half of that which would be done on a parabolic beam of the same *strength*. Equation 17 should, therefore, be—

$$\text{Work} = \frac{1}{6}\frac{\text{Vol.} \times f^2}{E} \quad \text{instead of} \quad \frac{1}{12}\frac{\text{Vol.} \times f^2}{E}$$

and substituting the true ratio of 3 to 1 instead of 2 to 1, as given in line 27, page 86, we obtain the expression—

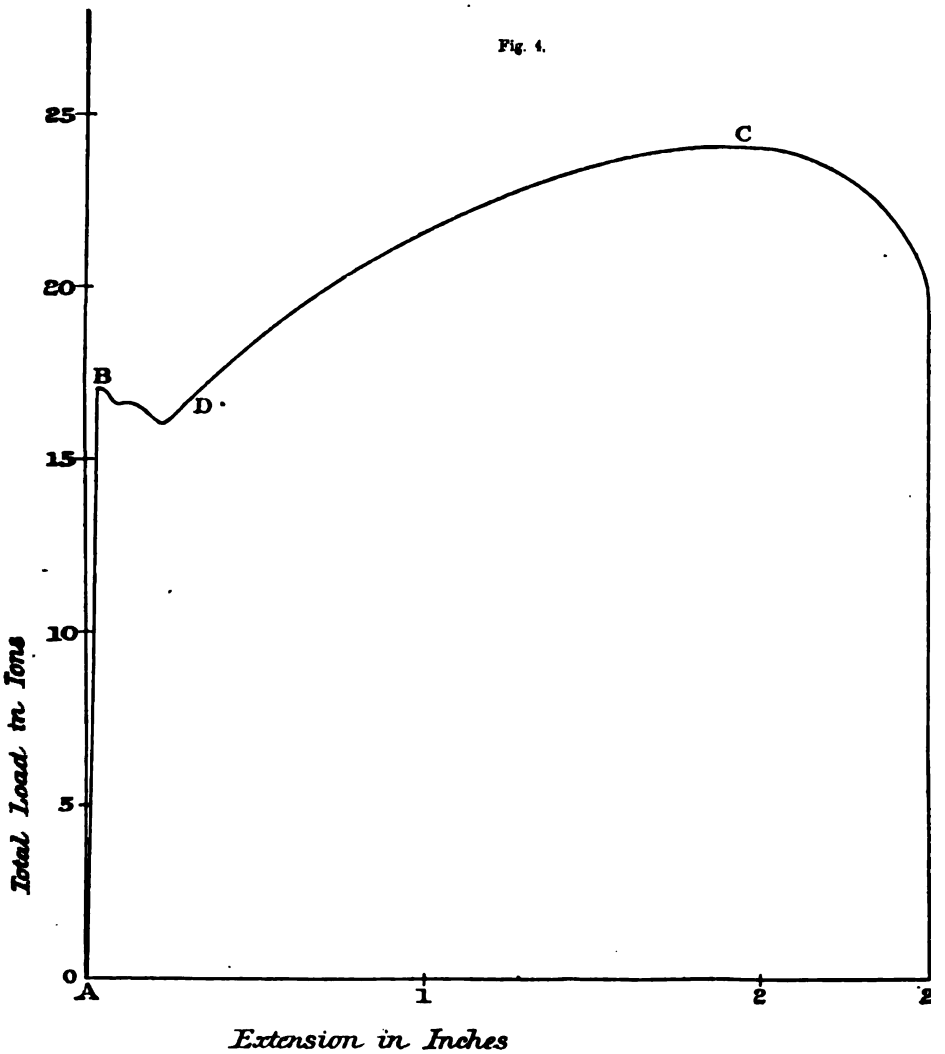
$$\frac{1}{6}\frac{\text{Vol.} \times f^2}{E}$$

for the work done on a beam of uniform strength, both from the "accepted theory" and from the "principle of work."

2.—Referring now to the second point, Mr. Spence had already dealt very fully with the question. The accompanying diagram, Fig. 4, was kindly lent by Mr. Wicksteed some time ago for another purpose. It illustrates the behaviour of mild steel under direct tension. It will be seen that the limit of elasticity is reached in a 10 inch

specimen at B, when the extension has reached only ·03 inch or ·003 of the whole length. The tension is then about 17 tons on the square inch. The steel then suddenly stretches till the whole extension reaches ·035 of the length without any sensible increase of tension. In fact

Fig. 4.



the automatic diagram indicates a diminution of tension at first, and the dip in the curve between B and D indicates an unstable condition, which must be passed over with a leap, by a specimen subjected to uniform tension throughout; but in the case of a bent bar, when the extreme

fibre reaches this state, the lateral cohesion of the fibre will come into play and give stability, since all are not equally stretched. Now, suppose that the extreme fibre is stretched by ·009 of its original length, and that the neutral axis remains undisturbed, then three-quarters of the portion of the bar subject to tension will sustain a tension nearly the same for all and equal to the elastic limit, but as the tension of no portion of the bar has exceeded that limit, and there is still a considerable portion which has not reached the limit, it may be that the bar will show no appreciable permanent set when the stress is relieved. If we suppose that the elastic limit for compression is the same as for extension, and that the behaviour of the material when that limit is reached, is similar in the two cases, the neutral axis will remain unchanged, and the stress diagram for the extreme section of the beam will be that shown in Fig. 5.

Fig. 5.

If the neutral axis remained unchanged, and the whole of the lower half of the beam were subject to the same uniform compression, and the upper half to the same uniform tension—an extreme condition to which we can, of course, only approximate—the load carried would be one and a half times that which caused the top fibre just to reach its elastic limit. If the limit of elasticity for compression were higher than for tension, as soon as the tension of the top fibre reached the elastic limit the neutral axis would move downwards, thus further strengthening the bar, so that the load might be increased 70 per cent., by loading only a very few of the fibres near the top up to their elastic limit. A very rough calculation shows that a shifting of the neutral line one-tenth of the height of the beam from the central line will leave ·447 of the volume stretched to its elastic limit, and increase the load carried by 80 per cent. The stress diagram for the extreme sections will then be that shown in Fig. 6. With beams of circular section the portions near the neutral line are of much greater relative importance than with beams of square section with their sides vertical. The extreme top and bottom fibres in the circular bars contribute comparatively little to the strength of the bar, and hence when the bar is on the point of taking a permanent set the plane which bounds the portion in which the stress is equal to the elastic limit from the other portion of the bar is nearer the neutral axis, and the tension of the extreme fibre calculated on the assumption that Hooke's law holds for it, *i.e.*, on the "accepted

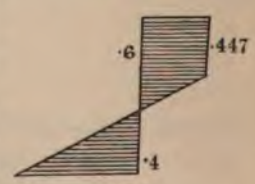


Fig. 6.

theory," becomes much greater than in the case of the square bar. In flanged girders exactly the opposite conditions obtain; the parts most distant from the neutral axis are those upon which the load mainly depends, and the stress in these portions becomes nearly uniform and equal to the elastic limit in the "accepted theory," so that the power of extension without further increase of tension does not cause the experimental results to differ sensibly from those of the "accepted theory" in the case of girders with narrow flanges. The stress diagram for a flanged girder in which the elastic limit has nowhere been exceeded is shown in Fig. 7, and it will be seen that the stress in each flange is nearly uniform. Similar remarks apply to all hollow beams or girders.

Fig. 7.

3.—Passing now to the question of the torsion of shafts, precisely the same principles apply. The modulus of the section for torsion in the case of circular sections is simply double that for transverse bending. When a solid shaft is twisted so as to approach the point of fracture a very large portion of its volume, and not simply the outside skin, will be sheared up to its elastic limit, and the work done will be very much greater than when the shearing reaches the elastic limit for the skin alone, which is the condition supposed in the "accepted theory." According to the "accepted theory," if we divide the shaft into thin tubes, while the volume of each is proportional to its radius, the amount of shear in it will also be proportional to the radius. Hence the work done per unit volume of any tube will be proportional to the square of the tube's radius, and the whole work on the tube will be proportional to the cube of the radius. Adding the amounts for each tube we obtain for the work absorbed by the shaft from the "principle of work"—

$$\frac{\text{Vol.} \times f_t^2}{4\,G}$$

where f_t represents the safe stress for shearing, which agrees with equation 9, page 102, and equation 16, page 103, for the work done on a helical spring and solid shaft respectively, and which have been deduced from the "accepted theory" by the author of the paper, so that here again the "principle of work," when properly applied, and the "accepted theory" are in strict accord. The work done if the whole shaft were exposed to simple shear to the elastic limit would be—

$$\frac{\text{Vol.} \times f_t^2}{2\,G}$$

or twice the above amount. In the case of hollow shafts the same prin-

ciples obtain as in that of flanged girders. When the internal diameter is not small compared with the external diameter a very large portion of the volume will be subject to a uniform shearing stress equal to the elastic limit before the shaft approached its point of fracture. When the internal diameter is nearly equal to the external diameter the stress becomes nearly uniform throughout upon the "accepted theory," so that in this case, as in that of flanged girders with very narrow flanges, the "accepted theory" agrees with experimental results. When a helical spring is under stress, the load line coinciding with the axis, the problem is precisely the same as that of the bar of which the spring is made being subject to torsion, and the same principles apply as in the case of the shaft. In all cases whether of bending or twisting, if the load is increased until a permanent set is produced the results cannot be compared with those predicted by the "accepted theory," for the reasons given above. To obtain experimental results consistent with the "accepted theory," the loading must cease as soon as the slightest divergence from Hooke's law can be detected. To test the views above expressed it is very desirable that careful experiments should be made on specimens in the condition indicated by the portion of the curve in Fig. 4, between the points B and D. As a portion of this curve corresponds to an unstable condition of the material, the experiments cannot be made on specimens subject to pure tension, but careful experiments on the bending of bars might throw some light on the question whether a specimen would take a permanent set if extended to the state represented by some point in the curve between B and D, and to this end it is eminently desirable that there should be a first-class testing machine in the hands of some public educational institution in the district.

Mr. Edward Reynolds, of Messrs. Vickers, Sons, & Co., Limited, said, he should not have ventured to take up any time that evening were it not for the fact that he was the first to take up his parable against hollow shafts. Having on former occasions spoken on the subject, he did not wish to repeat himself, but would rather, on the present occasion, qualify to some small extent what he had said, from considerations arising out of the present paper and discussion. He had unfortunately not been able to find time to read the paper word for word, nor could he claim credit for having devoted any of the small hours to it, as the Professor had done. On the general principle he might say that he thoroughly agreed with the author; at the same time, he should be surprised if the author dissented from what Professor Garnett had said; but these things had to be considered from two points of view—one, the

question of static strength, in which mathematical calculations were irrefutable; and the other, which, from his point of view, was more important—the dynamical question of how much work could be got out of material in different forms. In an article in the *Engineer* newspaper, upon the discussion on Professor Greenhill's paper (which had been referred to) it was remarked that Mr. Reynolds appeared to think that there was a hard and fast line between science and practice, to which he rejoined, that he was certain that there was a hard and fast line between the two, because our knowledge of the strength and endurance of material was and must be wholly experimental. It was a singular coincidence that his attention was first drawn to the subject, as the author's appears to have been, by experiments upon springs. Forty years ago, when he held the appointment of chief draughtsman in the locomotive department of an important railway, he tried, in view of the bad roads of that time, to reduce the strength of engine springs as far as prudence would allow, in order to get easier travelling; and the results of his experiments was, that when his old friend Mr. W. B. Adams (who's apprentice he had formerly been) showed him the system of ribbed spring steel which he had patented (he forgot the exact date, but it was about the time of Mr. Spencer's introduction of the volute spring), he laid down the law, that within such limits as were in question, the life of a spring was practically in proportion to its weight. Our knowledge was wholly at fault as to where the factor of safety begun which put us outside of this consideration. No doubt this factor ought to have reference to the elastic limit, and it was in this direction that it might be possible to increase our knowledge, for he thought it was not very clear where the elastic limit was. So far as he knew, Whitworth, the most recent introducer of hollow shafting, was one of the first (if not the first) to ask people to accept a break in the rise of a pressure gauge as indicating the elastic limit. Since that time the Woolwich authorities, working with the Thomasset gauge, had estimated their elastic limit in a similar way; this break in the regularity of extension being clearly shown in the diagrams produced by the Wicksteed Recorder (for which the engineering world were greatly indebted to Mr. Wicksteed, even though it was possible that his particular method of recording might be superseded by more simple arrangements). But though there can be no doubt that at this point there was generally a great disruption of the particles of a not very easily intelligible character, he (the speaker) had considerable doubt as to whether the true elastic limit had not been long past when this disruption took place. It was certain that the elastic limit so found was higher than the first perman-

ent set that could be found, by relieving the specimen of load and measuring by gauge points, but how much higher was uncertain. In the days of iron it was usual to test all the links of suspension bridges, these being generally of considerable length, say—in large bridges such as Chelsea bridge—20 feet, to about 10 tons per square inch; and he remembered being told—he thought it was by his friend Mr. E. A. Cowper, who was associated with Messrs. Fox & Henderson at the time when they made the ironwork for a large bridge in Russia—that careful observation on these long bars showed a permanent set as low as 3 tons per square inch; and he would suggest, as a most important matter for investigation, if Professor Garnett got the testing machine that had been referred to, that they should endeavour to ascertain whether this idea was well founded, or whether the ordinary idea of safe amount of extension or deflection was correct. It was possible that this idea of a very low point of permanent set might require some modification. At the same time that it did not lose its importance, that is to say, there might be a set which was not permanent. The writer's feeling was that it had been too much assumed that such substances as iron and steel were within the working limits perfectly elastic, but it was possible, if not probable, that the degree of imperfection of elasticity might be of more consequence than had been supposed. In the case of substances known to be imperfectly elastic, an archery bow, for example, it was notorious that the degree of flexure from which it would promptly recover if immediately released became more or less permanent if the flexure was long continued; moreover, that some recovery from the apparently permanently bent condition would take place in the course of time. The suggestion, therefore, was that the low set referred to in the bridge links might be only a temporary and not a permanent set, but it might nevertheless be an indication of a limit of strain which, if sufficiently often repeated, might induce disintegration of the material; as the fact that friction between the particles was obviously indicated by a temporary set, showed that there must be some actual dislocation of the particles, as distinguished from the mere modification of their form, which we could imagine to be the condition in a perfectly elastic body. The speaker considered this to be the process of failure from fatigue in machinery, which had been supposed from estimates formed upon known data, to be amply strong enough. At the same time the practical permanency of a great deal of machinery, under severe shock and strain tending to produce distortion, went to show that there was some limit within which practical permanency could be calculated upon. His protest against hollow shafting was founded more upon dynamic

considerations and the result of pretty wide experience than upon any calculation. No one could for a moment doubt the increased static strength of the hollow form, and he did not suppose that any of them would for a moment cavil at the use of hollow shafts, as steel-makers have to make them, to obtain sufficient rigidity within moderate weights to enable the shipowner to avoid numerous external brackets in twin screwships, in lengths sometimes exceeding 70 feet; but in the case of the internal machinery generally of a ship he should have considered that the object should be to give the greatest possible capability for elastic flexure for a certain factor of static strength, instead of reducing it by giving artificial rigidity, not only for the reasons formerly pointed out, viz., that any structure so perfectly proportioned that all parts were under equal proportional strain must fail suddenly, whereas experience had shown that in less mathematically proportioned structures the failure was generally gradual, but because, under the condition in which the most important machinery is used in steamships and on railways, the conditions of service generally involved serious strains, causing an uncertain amount of deflection apart from the steam strains, which could be easily calculated.

Mr. CRAWFORD said, he thought they were very much indebted to Mr. Foster for his many valuable experiments, although it had occurred to him that it was a pity that clear mathematical reasoning, applied on the assumption that an ideal perfect material was being dealt with, should have been so vigorously attacked because it did not, in one equation, fully account for the behaviour of matter under stress while passing from a state of rest through various fatigues until the moment when its destruction was imminent. Engineers, as distinguished from physicists, do not attach as much importance to the breaking stress of the material they are dealing with as its safe working load; and, therefore, he looked upon Mr. Foster's paper as a record of experiments ably carried out, but as not likely to affect the truth of the "accepted theories" he had attacked.

Mr. J. W. SPENCER said, he had come there that evening as a learner, and he was only sorry that there had not been a little more discussion upon the subject in the mathematical line. As far as the points had been developed, he thought Mr. Spence had advocated that the "accepted theory" would be identical with that of Mr. Foster, providing that the modulus of elasticity were assumed to vary with every variation in the cross section of the beam. He, however, failed to see how a factor which represented a property of the material (equally as much as its specific gravity or strength per square inch) could be assumed to vary with every variation in the shape of the bar or beam, and could therefore only be

determined for any particular form by an elaborate series of experiments. In the theory advocated by Mr. Foster, the modulus of direct elasticity was constant for similar materials within the elastic limit, and the transverse work-coefficients per unit of volume for all symmetrical cross sections under similar conditions of load, etc., were the same, and if that theory would enable engineers to calculate their varying structures with that approach to the truth, which was illustrated by the numerous tables of experiments, he thought Mr. Foster had arrived at a point of great utility. It was only since they had had the material—steel—that anyone could have been able to arrive at such uniform results as those which had been put before them that evening, for it was only with perfect materials that they were enabled to elaborate perfect results to base their theories upon. A man may scheme his bridge or other structure on the basis of a theory, and devote an immense amount of labour to his calculations, but, if the behaviour of the material which gave him his theory was not uniform, his theory would be at fault. He did not know that had he intended to enter into the discussion he should have said anything excepting on the strength of hollow shafting; and he must say that he entirely concurred with everything Mr. Reynolds had said. He might say that he was one of Mr. Reynolds' converts, for ever since he heard him speak on this subject several years ago, he (Mr. Spencer) had given a good deal of thought to it, and he had always been convinced of the soundness of Mr. Reynolds' contention at that time. His position in the present case was simply this—they wanted to have perfect formulæ for the calculation of springs; the accepted theoretical formulæ being such that they could not depend upon the calculated results, he therefore got Mr. Foster to go into the question with a view to obtain formulæ accurately expressing the strength and deflection of springs, and out of those experiments had devolved the "principle of work" theory. It was with very great pleasure that he afforded Mr. Foster the means to illustrate his paper, and he thought that a great deal of credit was due to Mr. Foster for the way in which the experiments had been carried out, even if the "principle of work" theory was not altogether correct.

Mr. H. Fownes said, few of them—while having ample means and the necessary material at their disposal for making any number of test pieces —however willing they might be to carry out experiments, had the opportunity and convenience for using a testing machine. He attended a meeting there a few weeks ago to see the plans for the New College of Physical Science when the question of the testing machine attached to the College was mooted and discussed. He was sure that if such a

testing machine was put down in that City, many of them would fully avail themselves of it, and a great many interesting facts and experiments would be deduced from it. He believed himself that the facility with which they could use it would really make it if not a commercial success, at any rate a self-supporting institution.

Mr. FOSTER'S reply was held over until the next meeting.

The following communication from Professor THOMAS ALEXANDER, of Glasgow, has been received :—

"The *resilience* or work stored up in a rectangular prismatic bar, such as that shown on Fig. 2, Plate 18, is truly given by the expression (2) page 83 of Mr. Foster's paper. The expression shows, that to graphically represent the *resilience* of a piece, whose fibres are under simple longitudinal strain, a *locus* must be drawn with ordinates proportional to the *square* of the stress on each fibre. We must then suppose C E to represent f^2 and not f, in order that the parallelogram D E may graphically represent the work stored up in the prism under longitudinal proof strain. To represent graphically the work stored up in the cantilever Fig. 2, Plate 18, having the proof load at its end, Mr. Foster's pair of shaded areas O C E and O D F must be altered in three respects:—First, the height C E must represent f^2 and not f; second the *loci* O E and O F, instead of straight lines, must be *parabola* having D C the tangent at their common apex O ; and here note that the area of the pair of shaded parabolic figures O C E and O D F will be *one-third* of the area of the parallelogram D E ; and in the third place, since the stress *varies* from section to section of the cantilever, a pair of parabolic figures must be drawn in the same manner on each cross section having heights less than C E, each height proportional to the *square* of the distance of the cross section from the weight. Then, of all these pairs of parabolic figures, that pair which has *average area* graphically represents the whole work stored up in the cantilever. By the algebra of the average of squares, that average area is *one-third* of the area of the pair of parabolic figures O C E, O D F. Therefore the *resilience* or whole work stored up in the cantilever, Fig. 2, Plate 18, under proof stress is *one-ninth*, and not one-half of that stored up in the same prism under longitudinal tensile proof stress. The expression (3) page 83 is wrong ; it ought to be—

$$\text{Work} = \frac{1}{18} \frac{\text{Volume} \times f^2}{\text{E}} \qquad \text{(A)}$$

and this expression, when thus corrected is exactly the same as the

expression (8) page 85, which Mr. Foster finds for the work done by the weight W in bringing the cantilever into the proof state of strain, strictly fulfilling the general law of the conservation of energy, namely that the work done by the weight in producing the strain is equal to the work done against the strength of the fibres when the strain is being produced. In general it is easier to calculate the *resilience* the first of these two ways as Mr. Foster does in finding (8), page 85 ; and the results found in this way are already tabulated by Professor Rankine in his Applied Mechanics, section 305, for most cases of transverse stress. There is no great difficulty in calculating results for any case by the second way, as Mr. Foster attempts at (3) page 83, and as I have correctly done in this letter, which results will be *always* found to agree with the others. If in any one case the results found these two ways did not agree, then Mr. Foster would be quite right in condemning Rankine's theory of transverse stress on the grounds that it violated the general law of the conservation of energy. In his paper Mr. Foster finds two expressions for the work stored in a uniform rectangular cantilever loaded with the proof weight at its free end, namely, the expression (3), page 83, by considering the work done against the elastic resistance of the fibres, in which f stands for the tensile proof strength of the material ; and the expression (8), page 85, by considering the work done by the weight. Because these two results are *different*, he condemns what he calls 'accepted theory,' as they ought to have been equal from the conservation of energy. He then introduces what he calls his 'principle of work,' and compels (8) to be equal to (3), by changing f in (8) into f_1, which he then calls the transverse strength of the material. Before equating (8) to (2), however, of which I shall write afterwards, he changes the numerical coefficient of (8) and it becomes (17), page 86. Equating (17) to (3) he obtains—

$$f_1 = f\sqrt{3},$$

upon which the whole of his paper is founded. As I have conclusively shown that (3) when correctly calculated is exactly equal to (8), all Foster's 'principle of work' disappears, and the whole paper, except the results of his experiments *per se*, is founded upon his own error. Before stopping I shall just show, quite apart from what I have already said, that the transition effected by Mr. Foster in changing (8) into (17) is effected by an assumption not at all *reasonable*, as he says it is, on page 86, line 11. First, then, I would point out that the equations (10), (11), (12), (13), and (14) are wrong. They refer to a cantilever of uniform strength and *width*, loaded at one end, and to correct them the numerical

coefficient of the last term of (10) must be changed to 8 instead of 6, and the consequence is that (14) ought to have been—

$$\text{Work} = \frac{1}{6}\frac{\text{Vol.} \times f^2}{\text{E}} \qquad \text{(B)}$$

Had Mr. Foster been referring to a cantilever of uniform strength and *depth* then his equations (10), (11), (12), and (13) would have been correct; but in passing from (13) to (14) he would then have required to use Vol. $= \frac{1}{2}bh\text{L}$, and (14) would have been—

$$\text{Work} = \frac{1}{6}\frac{\text{Vol.} \times f^2}{\text{E}} \qquad \text{(C)}$$

Now (B) and (C) are equal, so that in passing from (8) to (17) it would be equally reasonable to say that only half of the material was used to advantage from (C) as to say that two-thirds of the material was used to advantage from (B). In one case then (8) would be multiplied by $\frac{3}{2}$ to obtain (17); but in the other by $\frac{2}{1}$ to obtain (17). The fact that we can get two *equally reasonable* values of (17) derived from (8) shows that the alteration is entirely unreasonable. In conclusion, I may point out the curious use of the '*ad verecundiam*' made by Mr. Foster. He makes the following quotation from Baker, at the top of page 82, 'That the maximum deflection within the elastic limit is greater than theory would indicate,' as the *only* circumstance in which certain experiments were in *non-accordance* with theory; and then here is the use he makes of his quotation, page 84, line 22, 'As pointed out by Mr. Baker, the actual deflection of a beam is in ACCORDANCE with that indicated by 'accepted theory.'"

The following communication has been received from Mr. WILLIAM SISSON, of Falmouth :—

"Mr. Foster's paper is a very able and interesting development of a method of treating the problems of the strength of materials subjected to various stresses, by means of a coefficient usually called the *resilience* of the bar or beam, but which is more suitably termed by the author a 'work-coefficient.' The method appears to be quite a step in advance in relation to the well-known discrepancies between the moduli of rupture and the tensile or compressive strength of cast or wrought iron or steel beams. A very marked example of this discrepancy is manifested in the case of crane or coupling hooks.

Taking the example of the latter from Mr. Urquhart's practice (illustrated in *Engineering* of 10th December last), and calculating according to the ordinary methods the maximum tension on the inner side of the hook, it will be found that it amounts to about 35 tons, being made up of about 7 tons direct and 28 tons due to transverse stress, while it is not probable that the actual tensile strength is more than about 25 tons. Taking the author's notation, we thus obtain $f_1 \div f = \frac{28}{25 - 7} = 1{\cdot}55$. There can be no reasonable doubt, however, that there is no real *increase* of the tensile strength, but that, either from an alteration in the position of the neutral axis, or by reinforcement of the outer and more severely strained portions by their lateral adhesion to the inner layers, or, most probably, by a combination of these actions, the molecular resistance both acts with a greater total leverage, and the stress is more uniformly distributed than the usually 'accepted theory' indicates. It is clear that, if any change takes place in the position of the neutral axis, such change will be greater in amount, and result in more marked increase of the modulus of rupture in the case of beams, of materials such as cast iron, whose ultimate tensile and compressive strengths differ widely. Now, this *is* the case with solid cast iron beams, whose modulus of rupture is often, indeed usually, more than *double* the tensile strength, and especially in the case of small test bars, where the effect of the skin is relatively greater. Again, in regard to the effect of lateral adhesion of the material, it would be expected that, where this is inconsiderable (and at the same time where there is no great difference in the tensile and compressive strengths to cause change in the position of the neutral axis), the modulus of rupture would not differ much from either the tensile or compressive strengths. This is precisely the case with timber where the lateral adhesion or resistance to detrusion is perhaps $\frac{1}{20}$th the tensile strength, and, accordingly, the moduli of rupture will be found to be in most cases even *less* than the tensile strength, and on the whole may be reckoned a mean between the tensile and compressive strength. The great uniformity in the amounts of stresses, obtained by calculation on the author's general 'principle of work,' clearly indicate, I think, that this is the true basis of calculation, but a further investigation would probably bring out a consistent method of calculating the moduli of sections of beams and shafts so as to avoid the necessity of assuming the direct, transverse, and torsional stresses, all different, and in this connection it may be noted that St. Venant's investigations lead him to state the modulus of square shafting as

·281 × S^3 nearly, which gives a more uniform result still to the maximum stresses in the case of round and square shafting, the average maximum stress given for the latter on page 111 becoming about 33·4 instead of 35·384. If, again, the value of I_p (on page 109) be *not* affected by Professor Bauschinger's ratio (which, by the way, is apparently inverted, on page 108), and as it seems arbitrary to do so, for I_p is a determinate mathematical quantity and not a physical one; but if on the contrary (25) be stated in accordance with the author's principle thus—

$$\frac{6\ L\ R^2}{G\ S^4} \times W_1^2 = \tfrac{1}{2}\frac{S^2\ L\ f_1^2}{G}$$

there will result finally in (28)—

$$Z_t = \frac{1}{\sqrt{12}}\ S^2 = \cdot 289 \times S^2$$

which will make the maximum, though not the elastic, stresses still more nearly alike for square and round bars I was not aware that it was generally accepted that the polar moment of inertia of cross section divided by greatest distances of particles from centre of figure represents correctly the torsional modulus of even a square shaft and still less sections of greater irregularity. It will be found that there is a slight error on page page 85. (10) should read—

$$d = \frac{8\ W\ L}{E\ b\ h^3}$$

The deflection as given is that of a beam of uniform *depth* and strength, and, therefore, in plan a triangle, and of volume $\frac{bhL}{2}$.

This correction leads to the result—

$$\text{Work} = \frac{1}{6}\frac{\text{Vol.}\ f^2}{E}$$

(and this is true in the case of *either* form of beam, thus tending to confirm the author's theory of work in relation to volume). The reasoning on page 86 seems hardly to go as far as it may easily be carried, for if the *prismatic* beam be shaped into one of *equal strength* not only is there an increase in the work-coefficient due to the saving of volume, but an additional increase due to the increased deflection, thus taking the parabolic beam its deflection is double that of the prismatic beam, while its volume is two-thirds, thus we should infer that its work-coefficient would be increased in ratio of 2 × $\frac{3}{2}$ or 3, and referring to (9) this would give for the parabolic beam—

$$\text{Work} = \frac{1}{2}\frac{\text{Vol.}\ f^2}{E}$$

which makes the transverse 'work-coefficient' *equal* to the tensile 'work-coefficient.' Again considering the theoretical relation for the beam of *equal strength*—

$$\text{Work} = \frac{1}{6}\frac{\text{Vol.}\, f^2}{\text{E}}$$

and increasing this in the same ratio as the experimental result, for the *prismatic* beam is found to exceed the theoretical, there is found—

$$\text{Work} = 3 \times \frac{1}{6}\frac{\text{Vol.}\, f^2}{\text{E}}$$

that is— $$\frac{1}{2}\frac{\text{Vol.}\, f^2}{\text{E}}$$ as above.

Now this result (which appears quite legitimately obtained if (9) be correct) cannot be reconciled with (4), as it seems impossible to conceive that the molecular stresses in a solid beam are as uniform in intensity (though, of course, not in *kind*) as is the case in a bar subjected to direct stress. The conclusion, therefore, appears to be that it will be necessary to have recourse to experiment in order to determine the actual 'work-coefficients' of beams of forms of equal strength. I hope that my friend Mr. Foster will excuse these criticisms, assuring him that I have read his paper with great interest and profit."

The following communication has been received from Professor ALEX. B. W. KENNEDY, of University College, London :—

"I am very sorry that most severe pressure of work prevented me from examining Mr. Foster's paper in time to take any part in the discussion on it. I cannot say yet that I have had time to do it justice at all, but I welcome the long series of careful experiments as a valuable contribution to our knowledge of the strength of materials. From the theoretical point of view I am sorry that I am not quite able to agree with the author, which perhaps may be due to my not understanding him fully. But if the publication of the discussion is not yet completed, I should like to suggest to him, through you, that the equation (3), on page 83, on which I think the author's main (theoretical) contention depends requires other proof than that given in the paragraph preceding it, which I confess I have found quite unsatisfactory. I daresay Mr. Foster may have some other and more convincing form of proof of this matter, and if so, I think it would be advantageous that it should be given in his reply."

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886-87.

PROCEEDINGS.

FIFTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE SUBSCRIPTION LIBRARY, FAWCETT STREET, SUNDERLAND, ON WEDNESDAY EVENING, FEBRUARY 9TH, 1887.

W. THEO. DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the Minutes of the last General Meeting, held in Newcastle-upon-Tyne on 3rd instant, which were approved by the members present, and signed by the President.

The PRESIDENT said, before proceeding with the ordinary business it was his unfortunate duty to have to refer to the death of another of their prominent members. Mr. W. J. Clark, who had died since the last meeting, was a member of the Council of their Institution up to the end of last session, when he retired on account of his ill health ; he was also one of the Vice-Presidents. He (the President) was personally acquainted with Mr. Clark, and knew the great interest he took in every thing connected with their Institution. Owing to his training and mathematical knowledge he would have been a most useful member of their Institution had he been spared, but unfortunately it was not to be so, and they had now to deplore his untimely loss. He would now call upon Mr. Foster to reply to the remarks made upon his paper at their last meeting.

Mr. FOSTER said, in replying to the discussion on his paper, he might be excused if he prefaced his remarks with the following extract from the paper written by their late lamented member, Mr. Ivan Mavor:—"It has always been the order of progress that art goes first and afterwards science, and it may safely be laid down that it is necessary first to ground in practice, and then the study of the science becomes not only easier, but infinitely more interesting and instructive." It appeared to him that certain advocates of the "accepted theory" of the strength of structures were disposed to recognise that theory as absolutely unassailable, and wherever the facts, as illustrated by experiment, were at variance with their theory, "so much the worse for the facts," and instead of trying to explain the experiments, they tried to explain them away. This, he submitted, was not the course adopted by any one in search of truth. It had always been an established axiom in his mind that formulæ for the estimation of the strength of structures which did not represent their actual elastic or ultimate strength, as the case might be, were to the engineer worse than useless, since they only served him to make mistakes, and stood in the way of experimental enquiry. He expected considerable opposition to his views, and would have been disappointed had it been otherwise; but when it was considered that the "accepted theory" was opposed to the laws of conservation of energy, this in itself was sufficient eventually to silence all opponents.

Mr. Spence's opening and closing remarks were so directly opposed to each other that it was impossible to reconcile them. Firstly, Mr. Spence considered "that agreement with experiment was proof positive that the writer was in error," and conversely, that the disagreement between the old theory and experimental results was a strong argument in its favour, and afterwards "appealed to experiment in the endeavour to establish the accuracy of fundamental theories." In assuming that he (Mr. Foster) entirely ignored the elastic strength of a structure, and only referred to its ultimate strength, Mr. Spence was in error, as a very casual glance at the tables of experiments would show that both elastic and ultimate strengths were considered; and further, his assumption that the modulus of elasticity was only constant within the elastic limit, was also quite erroneous, as would presently be shown.

To the importance of referring all calculations of the strength of structures to their elastic limits no one could be more alive than the speaker, but when properly applied a true theory would equally apply, either when referred to the elastic limit or to the ultimate strength, as would be apparent from the following simple illustration:—Suppose a

bar of steel or other material having a tensile elastic limit of fifteen tons per square inch and a maximum strength of thirty tons to be placed in the testing machine and a tensile strain applied ; then so long as the elastic limit of fifteen tons per square inch was not exceeded, the elongation of the bar would be directly proportional to the load applied; if however the elastic limit was exceeded the bar would take a "set," and would continue to do so as the load was increased. After reaching twenty tons per square inch suppose all strain to be removed and the experiment commenced over again, it would now be found that the elongation was proportional to the load applied, up to, or nearly up to, the point where the experiment had been previously discontinued; in other words, the elastic limit would be pushed up from fifteen to twenty tons, and any one afterwards testing the bar, and being ignorant of its previous treatment, would register its elastic limit as twenty tons per square inch. In the same way the elastic limit of the bar could be gradually increased until it nearly coincided with the maximum strength, and the elasticity of the bar would be perfect from zero nearly up to its breaking strain. To assume therefore that when the first elastic limit was exceeded, that the bar was no longer elastic was quite erroneous, for probably in more than 999 springs out of every 1,000 manufactured, the first elastic limit was thus lifted up, and advantage taken of the increased elastic strength thereby induced. In drawing their diagrams of strain both Mr. Spence and Professor Garnett neglected to distinguish between the diagram of work and the diagram of "set," and apparently forgot that there were two elements at work when a bar was being broken ; one, the load overcoming the bar, the other the bar overcoming the load. The effect on the bar produced by the load at any given instant was represented by the diagram of work, plus the diagram of "set," while the diagram of work alone represented the resistance offered by the bar. Thus, in Mr. Spence's diagram here reproduced, where the line C E coincides with the elastic limit, the triangle A C E would represent the work done both by the bar and the load up to the elastic limit, and the triangle A B F the total work done by the bar up to its maximum strain, while the whole triangle A B F, plus the diagram of "set" C D F, would represent the effect produced by the

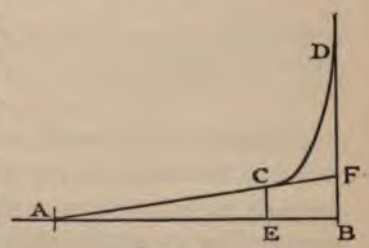


Fig. 8.

load in breaking the bar. When the diagram of "set" was thus eliminated (as it always should be), the modulus of elasticity was practically constant both above and below the elastic limit. To prove this the following method of procedure was adopted in conducting the experiments on helical springs, illustrated in Plates 21, 22, and 23. The springs were first tested in their unhardened state, the deflection per increment of load being carefully registered, and the loads removed after each addition to ascertain "set." After each spring had been thus tested "home," all load was removed and the spring tested over again. They were then heated to a bright red heat, set up to their original height and hardened and tempered in the ordinary way, after which they were tested once more. The results obtained from all the springs being uniform, it is only necessary to give those obtained from spring (A) as an illustration.

SPRING (A). (UNHARDENED.)

Height before testing = $13\frac{1}{16}$"
„ after „ = $12\frac{13}{16}$"

Load in cwts.	5	10	15	20	25	30	35	40	45	50	
Deflection in inches ...	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{16}$	$1\frac{5}{16}$	$1\frac{7}{16}$	$1\frac{3}{4}$	$2\frac{5}{16}$	$2\frac{11}{16}$	$3\frac{1}{8}$	
Set „ ...							$\frac{1}{16}$	$\frac{1}{8}$	$\frac{7}{16}$	1	

(TESTED OVER AGAIN.)

Load in cwts.	5	10	15	20	25	30	35			
Deflection in inches	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$			
Set „										nil.

Spring (A) after being heated to a bright red heat, and hardened and tempered—

Height before testing = $13\frac{3}{8}$"
„ after „ = $13\frac{1}{16}$"

Load in cwts.	5	10	15	20	25	30	35	40	45	50	55	60	65	70
Deflection in inches...	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{7}{16}$	$1\frac{3}{4}$	$1\frac{15}{16}$	$2\frac{1}{8}$	$2\frac{3}{8}$	$2\frac{5}{8}$	$2\frac{13}{16}$	$3\frac{3}{16}$	$3\frac{1}{2}$
Sets „ ...											$\frac{1}{16}$		$\frac{1}{8}$	$\frac{7}{16}$

A comparison of the results obtained under the three conditions would show that the deflections per increment of load were almost identical, and therefore proved that the modulus of elasticity of the material was not altered either by testing above the elastic limit or by hardening; the hardening simply raised the elastic limit without altering the deflections per increment of load.

The deductions of Professors Garnett and Alexander in reference to pages 83 to 86 of the writer's paper were identical, but in assuming that

the paper was entirely founded on the reasoning there given they were quite in error, for as a matter of fact it was never afterwards used, for reasons which would presently appear obvious.

By trusting to a standard German text book on Machine Design, he (Mr. Foster) had been led into an error on page 85 of his paper, where formula (10) instead of—

$$d = \frac{6WL^3}{Eb h^3}$$

should have been—

$$d = \frac{8WL^3}{Eb h^3}$$

And in the case of the beams illustrated by Figs. 1, 2, and 4, Plates 18 and 19, the diagrams of work had been drawn wrong in order to lead to controversy, and eventually to the recognition of a third element of strength in beams, generally ignored, but which was known to exist, and which was absolutely necessary in order that the "principle of work" might be true, and he was pleased to find that Professors Garnett and Alexander had so kindly responded to the inducement held out, for he would be able to show wherein they were in error. On the assumption that there were only two elements of strength in a beam under transverse strain, namely, the resistances to direct compression and extension, the learned gentlemen determined the work-coefficient of a beam of uniform rectangular cross section throughout its length, fixed at one end and loaded at the other, to be represented by the formula—

$$\text{Work} \times 2 = \frac{1}{9} \frac{\text{Vol.} f^2}{E};$$

or,

$$\text{Work} = \frac{1}{18} \frac{\text{Vol.} f^2}{E},$$

which was the same as that given in the paper on page 85, No. 8. As a matter of fact, however, the *actual* work equivalent *within* the elastic limit was three times the value here given, or equal to

$$\text{Work} \times 2 = \frac{1}{3} \frac{\text{Vol.} f^2}{E}.$$

Now he was certain about this, for the very sufficient reason that he had tried it over and over again, and was able to show where the discrepancy occurred, for in conducting the experiment it soon became apparent that the deflection per increment of load was faithfully given by the formula—

$$d = \frac{WL^3}{3EI} = \frac{4WL^3}{Eb h^3};$$

but the maximum deflection *within* the actual *elastic limit* was $\sqrt{3}$ times more than the tensile or compressive strength of the material would warrant, requiring of course $\sqrt{3}$ times the theoretical safe load to produce it, giving three times the theoretical work-coefficient. Again, during the winter of 1884 and 1885 he had conducted experiments on beams of uniform depth throughout their length, fixed at one end and loaded at the other, and gradually tapering in width until they assumed the form of uniform strength and depth shown in Fig. 9; and here, too, he had found that the deflection per increment of load was faithfully given by the theoretical formula—

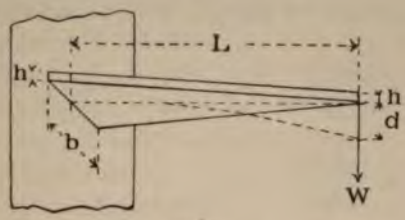


Fig. 9.

$$d = \frac{6WL^3}{Ebh^3},$$

but that the deflection within the elastic limit, and the load to produce it, were each 73 per cent. more than the actual elastic strength of the material would warrant, so that the *actual* work-coefficient of this form of beam within the elastic limit was—

$$\text{Work} = \frac{1}{2}\,\frac{\text{Vol.}\,f^2}{E},$$

and not

$$\text{Work} = \frac{1}{6}\,\frac{\text{Vol.}\,f^2}{E}$$

given by Professor Alexander. He had not experimented with beams of uniform strength and width, and of variable depth, but he did not doubt that here, too, the same relationship would be found to apply. It would therefore be evident why he always distinguished between the transverse stress f_1 and the tensile stress f, and how the relationship—

$$f_1 = \sqrt{3}f$$

had been obtained. His paper was therefore not founded upon an error, as Professor Alexander had assumed, but upon an absolute fact, determined by experiment; and in assuming that *only* in the case of Baker's experiments were the strength of beams in non-accordance with theory, the learned Professor was altogether in error, in proof of which the writer begged to refer him to the experiments of Hodgkinson, Barlow, Kirkaldy, Kennedy, Wöhler, and many others. But possibly a person was never so

thoroughly convinced as when he convinced himself, and if Professor Alexander would compare the actual work done with the volume of material used in laminated springs on the thousands of wagons running on our railways he would find his determinations absolutely inadmissible. Professor Garnett recognised the fact that the transverse strength of a solid bar was very much in excess of that calculated by the "accepted theory," and accounted for the discrepancy by assuming that the neutral axis shifted when the top or bottom fibres were strained above their elastic limit; but the fact remained that the calculated stress on these fibres was over 70 per cent. more than that capable of permanently stretching or compressing them before any "set" was observable. Again, in bars of hardened tool steel, where the elastic limit and the breaking strength were identical, the same discrepancy was observed; and furthermore, he (Professor Garnett) was not justified in any such assumption by the results of Barlow's experiments, from a description of which the following extracts had been made* :—

"It has long been known that under the existing theory of beams, which recognises only two elements of strength, namely, the resistances to direct compression and extension, the strength of a bar of cast iron subjected to transverse strain cannot be reconciled with the results obtained from experiments on direct tension if the neutral axis is in the centre of the bar."

"The experiments made both on the transverse and the direct tensile strength of this material have been so numerous and so carefully conducted as to admit of no doubt of their accuracy; and it results from them either that the neutral axis must be at or above the top of the beam, or there must be some other cause for the strength exhibited by the beam when subjected to transverse strain."

"I was desirous that the experiments for determining the position of the neutral axis should be made on such a scale and in such a manner as to place this question beyond doubt; and with this object the following means were adopted."

Mr. Barlow then goes on to give the particulars of his experiments on two beams, and to describe the apparatus for taking the measurements, and says :—

"The measurements were taken four times in each position of the beam, and the error of measurement did not generally exceed from one to two divisions (each division was equal to $\frac{1}{4300}$ of an inch), but if in the four observations an error amounting to more than four was found, it was corrected by remeasurements. * * * In these experiments more than 3,000 measurements were taken."

And Mr. Barlow afterwards remarks :—

"The results exhibit more regularity than could have been expected, and they point out the position of the neutral axis as the centre of the beam in a manner so decided as

* *Transactions of the Philosophical Society*, 1855.

to remove all further doubt upon this subject, not only in the smaller strains but in the larger ones also; which in the case of the second beam were carried to about three-fourths of the breaking weight."

It would therefore be obvious from the results of these experiments, that the discrepancy referred to had to be accounted for by some other assumption. Professor Garnett seemed to think that he (Mr. Foster) doubted the truth of Hooke's law (*ut tensio sic vis*). This, however, was an error, for in reality he had shown that in the harder qualities of steel, when the diagram of work was distinguished from the diagram of "set," Hooke's law was applicable nearly up to the breaking strain; and the learned Professor's statement that "to obtain experimental results consistent with the 'accepted theory,' the loading must cease as soon as the slightest divergence from Hooke's law can be detected" was very misleading, because Professor Kennedy had shown that in a bar of mild steel subjected to tension for the first time after manufacture, a small permanent "set" was observable with apparatus sufficiently delicate, with a load of about one-third the breaking load, but that, nevertheless, the extensions were proportional to the tensions up to about one-half the breaking load. These small permanent "sets" it was well known were due to the presence of initial strains in the piece, and might be induced by unequal cooling of the test bar; and it had been pointed out by Mr. Percy Vavasseur Appleby* that in testing a bar to obtain its modulus, it was advisable to strain the bar to about three-quarters of its limit before commencing to record the readings. It was not, however, generally known that by first hardening and tempering a helical spring, then gradually straining it above its elastic limit, and afterwards submitting it to rough usage, made it absolutely uniform in its working results, that is, in strict accordance with Hooke's law, but as an illustration of this fact he gave the following results of experiments:—

Test of a helical spring after being squeezed "home" and receiving considerable permanent "set":—

Deflections in inches ...	$\frac{1}{4}$	$\frac{1}{2}-$	$\frac{11}{16}$	$\frac{15}{16}+$	$1\frac{3}{16}$	$1\frac{7}{16}$	$1\frac{11}{16}$	2	$2\frac{3}{16}+$	$2\frac{1}{2}$
Loads in cwts.	10	20	30	40	50	60	70	80	90	100

— means bare. + means full.

The same spring, after having been struck 2,000 blows under a 12 cwts. steam tilt hammer, striking 260 blows per minute; deflection under each blow = 2″:—

Deflections in inches	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$
Loads in cwts.	10	20	30	40	50	60	70	80	90	100

* Inst. of Civil Engineers, *Proceedings*, Vol. 74.

It would be observed that after the severe treatment the spring had received it gave equal deflections per increment of load, which was not the case previously; it was also interesting to add that the spring was so hot after the hammering that the hand was burnt in touching it. Before being tested, however, the spring was allowed to cool to its normal temperature, and he recommended a somewhat similar treatment when springs were required for indicators and similar instruments, where uniform deflections for uniform increments of load were absolutely necessary.

He was pleased to find that Mr. Reynolds agreed with him, and that their mutual attention had been drawn to the subject by experiments upon springs, because he considered that springs (wherein both elasticity and strength were required) afforded us the best possible means of studying the strength and endurance of materials. He agreed with Mr. Reynolds that our knowledge of the factor of safety which would afford us a permanent structure under dynamical loads was very limited, and thought with him that the factor of safety should have reference to the elastic limit, and he did not think that any artificial means of raising the elastic limit of a material which did not at the same time raise its ultimate strength would add to the endurance of that material. Oil hardening and tempering would, he believed, add to the endurance of steel, because both the elastic limit and breaking strength were raised thereby, without very much altering the percentage of elongation before fracture, and in this direction he believed that great results would ultimately accrue from the experiments on "Fatigue of Metals," commenced by Wöhler, and since repeated by Spangenberg and others.

He was pleased to find that Mr. Sisson recognised the "principle of work" theory as a step in advance, and that Mr. Sisson had observed, what he (Mr. Foster) had endeavoured to hide, for purposes already explained, viz., that the transverse work-coefficients of ordinary constructive materials, when distributed to the best advantage, were equal to their tensile work-coefficients. Of course this could only be true with materials which were equal in strength and equally elastic, no matter in which direction the test piece was cut; with wood, the lateral adhesion of the fibres was very small, and its behaviour under transverse strain was something similar to that of a laminated spring, which, though not so *strong* as a solid beam of equal depth, was very much more elastic. With regard to the position of the neutral axis of a beam, it was evident from the experiments of Hodgkinson on cast iron beams of varying ratios of tension and compres-

sion flanges,* that it was not very far from the centre of gravity of the cross section, but he thought that in determining its position, the relative moduli of elasticity of the material in tension and compression should be carefully considered; because where one was greater than the other the neutral axis would be above or below the centre of gravity as the case might be, and the strength of the beam somewhat modified thereby. He did not agree with Mr. Sisson that it was arbitrary to alter the polar moment of inertia (I_p) for a square bar, as had been done on page 109 of his paper. He was glad, however, that his motive for so doing had been questioned, because it afforded him an opportunity of fully stating his reasons. From the formula—

$$d = \frac{LR^2W}{GI_p}$$

representing the deflection of a helical spring as given on page 101, it was evident that—

$$G = \frac{LR^2W}{I_p d},$$

and if the theoretical values of $I_p = \frac{\pi}{32} D^4$ for round bars, and $I_p = \frac{1}{6} S^4$ for square bars be substituted, and the formula used to determine the values of (G) from actual experiments on helical springs made from round and square bars respectively, it would be found that the values of (G) for round bars were always greater than for square bars, although both kinds of springs had been made from the same piece of steel. The trouble, however, did not end here, for if the experiments were continued on helical springs made from oblong cross section bars as shown in Fig. 10, and Reuleaux's value of—

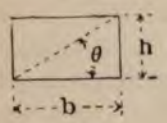


Fig. 10.

$$I_p = \frac{1}{6} \frac{2b^3h^3}{b^2+h^2} = \frac{1}{3} \frac{b^3h^3}{b^2+h^2}$$

be substituted, it would be found that the values of (G) varied with every alteration in the ratio of thickness to breadth of bar; but (G) was a property of the material and could not be assumed to alter with every alteration in the form of cross section, and therefore the writer had altered the value of (I_p) for square bars so that (G) might be constant, and he had found by plotting the results of an extensive

* Memoirs of the Literary and Philosophical Society of Manchester. Second series, Vol. 5.

series of experiments on helical springs made from oblong cross section bars of varying ratios of thickness to breadth, that the value of (I_p) for any rectangular bar was—

$$I_p = \left(\frac{b}{5\sqrt{b^2 + h^2}}\right)\left(\frac{2b^3h^3}{b^2 + h^2}\right) = \frac{1}{5 \text{ Sec } \theta}\left(\frac{2b^3h^3}{b^2+h^2}\right)$$

which for a square bar became—

$$I_p = \frac{1}{5\sqrt{2}} S^4$$

as given on page 109 of the paper, from which it followed on the writer's general principle that—

$$\frac{5 \text{ Sec } \theta \text{ LR}^2}{\text{GS}^4} \times W_1^2 = \frac{1}{2} \frac{\text{Vol. } f_t^2}{\text{G}},$$

from which the modulus of section Z_t could be determined for any rectangular bar, as shown on page 109.

In conclusion, he begged to thank the President and Council of that Institution for the publicity given to his paper, and for the opportunity they had afforded him of replying to the criticism which it had evoked.

The PRESIDENT said, he thought they would all agree that the beautiful and extensive tests that had been made by the writer of the paper were almost invaluable; that the paper, as a whole, was equal to any that they had yet had, and one that was worthy of being read before any of the institutions of the country. The discussion also would be very valuable additions to their Transactions, and he had very great pleasure in proposing a hearty vote of thanks to the writer of the paper.

Mr. STIRZAKER endorsed the remarks of the President. The paper had been one of the most interesting which had been read before the Institution, at least to the engineering section of it. It had received a great deal of adverse criticism, very rightly so in his opinion, for he had spent three evenings in reading it, and had come to the conclusion that the deductions were wrong. He entirely agreed with Professor Garnett's

reasoning, He considered it would have been well if more of the paper had been devoted to hollow shafting and less to beams. He thought that the most practical way of calculating the strength of beams was not from the tensile strength of the material but from the transverse strength of it, as obtained from a test bar, because beams were subjected to both tensile and compressive strains. He was sure Mr. Foster would take in good part all that had been said about his paper. He had great pleasure in seconding the motion.

The motion was carried by acclamation.

Mr. FOSTER said, in thanking them for their vote of thanks, he was only there in the interests of truth, and he would be pleased to meet Professor Garnett again when he (Professor Garnett) got his testing machine, for it was absurd to argue against facts. His theory of the torsional strength of hollow shafting was proved by experiments which could not be gainsaid, and he would be glad to see these experiments repeated on a larger scale, in the presence of representatives of the Admiralty, Board of Trade, and Lloyd's Register. He thanked them very kindly for their vote of thanks.

The following paper on "Some Notes on the Launching of Vessels," by Mr. H. G. Gannaway, was then read :—

SOME NOTES ON THE LAUNCHING OF VESSELS.

By H. G. GANNAWAY.

As no papers upon launching have yet been read before this Institution, and the subject is one that has not even in older institutions received the attention that it deserves, it will perhaps be a suitable one for consideration now, more especially as in recent years many of the vessels built in this district have reached very considerable dimensions, even if we left out of consideration war vessels, and others of special types, and thus require much more study than has possibly been hitherto paid to this matter.

The main object of this paper is to deal with the form of launch ways, and to point out the effect of variations of curvature and declivity. The limits of time available for a paper of this nature render it impossible to deal with many other points of interest, which could each furnish a subject for a separate paper.

In vessels of moderate size, and not differing in any material features from the ordinary type, the difficulties and dangers incurred in launching although considerable, are usually successfully coped with, and do not require any special mode of treatment either in calculation or in the practical carrying out of the work. In most shipbuilding yards, therefore, the laying of the ways for such vessels is left mainly in the hands of the foreman shipwright, who, in fixing the declivity, is guided by his experience of other launches, which generally leads him to a reasonably successful result. It is, however, evident that such a system while being wholly unfit for unusual types of vessels may even, in ordinary ships, occasionally lead to failure, or very near it, and as the trouble and expense of working upon a more correct method is not very great, it is questionable if it would not be more satisfactory, even in ordinary cases, to pay somewhat more attention to the launching arrangements than is now generally done.

The form of ways for ordinary merchant ships is of comparatively little importance, but in special cases, such as armoured war vessels or long light river boats, if there is too little water on the way ends the

vessel is liable to tilt as soon as her centre of gravity gets over the way ends, and being as it were pivoted at this point, a great pressure is put upon the bottom of the vessel, causing undue local strains, which might possibly force in the bottom plating, frames, etc., in these vessels which are not so strongly constructed locally as ordinary merchant vessels, or the ways might give way here, and then the vessel would be left to slide off the remainder of this distance on her keel. To guard against this danger it is desirable to ascertain by calculations and diagrams if the form of the ways is such that the vessel may be launched without fear of tilting.

Before going into an analysis of the data given in the table of launching particulars, it may be well to trace the movements of a vessel, from the time when she first commences to move until she is afloat. The time that a vessel takes to travel down the ways may be divided into two periods, the first lasts while she is bearing entirely on the ways, and the second when the stern is afloat, and the fore end of the ship is bearing on the fore end of the sliding ways. To show when the change takes place between these two periods, we will take for an example the vessel illustrated in Plate 25, Fig. 1, where she is shown in three positions, namely, A the commencement of the first period, B the change between the two periods, and C the end of the second period respectively, thus showing the relative lengths of the periods.

We now come to the curves illustrating the varying conditions during the whole of both periods, which are given on Plate 25, Fig. 2. These are constructed as follows:—A base line is first drawn the measurements along which represent distances travelled by the ship down the ways, the total length being in this instance 267 feet. The line A A, drawn parallel to the base, represents the moment of the ship about the fore end of the sliding ways. In this example, the ship's weight is 865 tons, which being multiplied by 97·25 feet, the distance of its centre of gravity from the fore end of the sliding ways = 84,121 foot tons. The buoyancy moments about the same point are represented by the curve B. The position of intersection of this curve with the line A A indicates where the vessel will be when her stern commences to float aft. At this point the first period ends and the second commences, which, in the example before us, is when the vessel has travelled 208 feet 6 inches down the ways. Although this is the point where the moments of buoyancy and weight about the fore end of the sliding ways become equal, the vessel's stern does not actually lift until she has moved a few feet beyond this, because an additional amount of displacement is required to overcome the

vertical component of the ship's momentum. Observations of the dip of the vessel's heel have proved that this additional displacement is so trifling, that a complete investigation of its amount is unnecessary for ordinary purposes. The displacements of the vessel throughout the first period are shown by the curve D_1, and for the second period by the curve D_2. During the second period, the after end of the vessel being afloat and the fore end resting on the fore end of the sliding ways, it is evident that the buoyancy moment about that point will remain the same as the weight moment all throughout this period. The displacement, of course, increases as the vessel moves down the ways, but the gradual lifting of the stern and lowering of the bows brings the centre of buoyancy further forward, and so reduces the leverage while the displacement is increasing, thus retaining practically a constant moment. The distance that the line C C is above the base represents the weight of the ship, the weight on the fore end of the sliding ways being proportional to the distance between this line and the curve of displacement D_2. This weight is 225 tons at the beginning of the period, and is reduced to 115 tons at the end. It is, therefore, important that the fore end of the cradle should be made sufficiently strong to carry the load which is thus put upon it. It will be seen, then, that it is desirable to reduce the duration of the second period as much as practicable, for since the longer it is, the greater the weight will be on the fore end of the sliding ways, which, in the case of heavy vessels, renders them liable to come down on the ground and damage their fore ends.

In considering the subject of tipping we take the moments about the end of the standing ways, and as long as the buoyancy moment remains in excess of the weight moment about this point there is no fear of the stern tilting ; but if in any position the former moment falls short of the latter it is evident that, in order to restore equilibrium, the stern will drop and thus increase the displacement until both moments become equal. Tipping, of course, if occurring at all, must take place after the centre of gravity of the ship has passed the end of the standing ways and before the commencement of the second period. In the vessel now before us the centre of gravity passes the way ends when she has moved a distance of 174 feet. From about this point to a little beyond the end of the first period the buoyancy and weight moments about the end of the standing ways are calculated at several intervals, at each interval the latter moment being deducted from the former gives the moments against tipping ; these moments are shown by the curve E. If this curve at any part was to run below the base line it would show

that the vessel will tilt. The point where this curve is nearest to the base line gives the position of the vessel when she has least longitudinal stability, which in this case is when the vessel has travelled down the ways a distance of 189 feet, the minimum margin against tipping being 9,700 foot tons. It is desirable that this margin should not be too small, for in certain vessels where this was the case they actually did tilt slightly, which shows that a moderate margin is required in calculation to allow for the error introduced by treating, as it is convenient to do in practice, these moments statically instead of dynamically. In calculating the buoyancy moments no account is taken of the cradle, which would only alter the results slightly, the variations being on the right side may be safely ignored. Besides the after end of the sliding ways often rise to the surface shortly after the vessel has entered the water. In the diagram a complete set of curves have been given to fully illustrate the matter, but for practical purposes only that part of the diagram where the vessel is represented to be moving from the position where the centre of gravity is at the way ends to the end of the first period is required. This portion is shown separate on Plate 25, Fig. 3, where the measurements along the base line represent distances that the middle of the vessel is from the way ends instead of distances travelled from the first start.

As the minimum moment against tipping is a very important thing, it will be useful to know what variation will be made in its amount by any alteration to the length and form of the standing ways of this vessel. This will be as follows:—Lengthening the standing ways 10 feet increases this moment from 9,700 to 13,700 foot tons; shortening the ways 10 feet decreases the moment to 5,300 foot tons; increasing the camber from 12 to 18 inches has the effect of bringing the moment up to 14,500 foot tons, and by decreasing the camber to 6 inches the moment is reduced to 4,000 foot tons.

If with a certain declivity of ways for the launching of a vessel it is found by calculation that she will tilt, the standing ways must be extended further out into the water, or, if this cannot conveniently be done, their outer ends must be lowered, or ballast put into the fore end of the vessel. The first two methods increases the buoyancy moment about the end of the standing ways, and the third one decreases the weight moment about the same point.

Having investigated the successful launch of the vessel on Plate 25, Fig. 1, we will take as an example of an unsuccessful launch the steamer M on the table of particulars of launches. This vessel having to be towed

to another port to receive her machinery had over 600 tons of water ballast on board so that she would be ready to proceed to sea immediately after being launched. The weight of the vessel in this condition was 1,750 tons, and there was barely 2 feet of water on the end of the ways. When the dog-shores were knocked down she started off immediately, and being very heavy travelled down the ways at a great speed until her centre of gravity got past the way ends, when her stern dipped to such an extent that the ways were broken by the great weight put upon them at this point, and the vessel had to slide off the remainder of the distance on her keel. The bottom plating amidships was buckled and a pillar in the boiler space was bent, but not making any water she proceeded on her voyage. In order to have launched this vessel safely with all this ballast on board the ways would require to have been extended about 50 feet further out, which would give 3 feet more water over their ends than there actually was. Had she been launched with her ballast tanks empty there would not have been sufficient water by several inches to prevent her tilting; however, by filling the fore peak only with water she could have been launched without fear of tilting.

In the table of launching particulars, page 154, will be found the launching data of twelve vessels of various sizes, the launching displacements varying from 2,850 tons down to 215 tons. The length, breadth, and area of the sliding ways are given and the mean pressure per square foot on the sliding ways. This pressure varies from 2·63 tons in the vessel M, which was launched with a large quantity of water ballast on board, to ·57 tons in the light paddle steamer K. In this table will be found the lengths in feet of both periods, also the ratio of the length of the second period to the length of the sliding ways, which ratio varies from 23 to 50 per cent., the lowest percentage occurring in the cases where the moment against tipping is comparatively small, and the highest where this moment is large. All the vessels, with the exception of the two designated L and M, went off without tipping, the margin of safety in foot tons varying from 80,000 down to 5,500. The vessel A, which is a heavy war ship, if allowed to tip, would very probably have damaged herself; and in order to obtain the comparatively small margin against tipping of 10,500 foot tons the ways had to be run out as far as possible and their ends kept down very low, causing the declivity at this point to be very steep, namely, $1\frac{1}{8}$ inches per foot. The vessel B was launched with her engines and boilers on board and had a margin against tipping of 33,250 foot tons, which appears moderate and shows that the form of the ways was very suitable for her. The next four vessels C, D, E, and F, are cargo vessels and each having pretty full lines, possess considerable moments in

TABLE OF LAUNCHING PARTICULARS.

	A.	B.	C.	D.	E.	F.	G.	H.	J.	K.	L.	M.
	Twin Screw War Vessel.	Screw Steamer.	Screw Steamer.	Screw Steamer.	Screw Steamer.	Screw Steamer.	Screw Steamer, Fine Lines.	Screw Steamer.	Sailing Vessel.	Paddle Steamer.	Screw Steamer, Fine Lines.	Screw Steamer.
Moulded dimensions of vessels, in feet	300×56×37	360×36×28	400×42×29½	360×42½×29	330×43½×30½	280×36×24	270×34×19	234×33×18	220×35×22	190×22×9	270×32½×19	250×35×23
Declivity of keel per foot	$\frac{9}{16}$″	$\frac{5}{16}$″	$\frac{5}{16}$″	$\frac{5}{16}$″	$\frac{9}{16}$″	$\frac{5}{16}$″	$\frac{9}{16}$″	$\frac{9}{16}$″	$\frac{5}{16}$″	$\frac{9}{16}$″	$\frac{5}{16}$″	$\frac{9}{16}$″
Declivity of standing ways per foot ...	$\frac{5}{16}$″ to $\frac{15}{16}$″	$\frac{5}{16}$″ to $\frac{13}{16}$″	$\frac{5}{16}$″ to $\frac{11}{16}$″	$\frac{5}{16}$″ to $\frac{11}{16}$″	$\frac{5}{16}$″ to $\frac{15}{16}$″	$\frac{5}{16}$″ to $\frac{15}{16}$″	$\frac{5}{16}$″ to $\frac{13}{16}$″	$\frac{5}{16}$″ to $\frac{14}{16}$″	$\frac{5}{16}$″ to $\frac{14}{16}$″	$\frac{10}{16}$″ to $\frac{14}{16}$″	$\frac{5}{16}$″ to $\frac{14}{16}$″	$\frac{9}{16}$″ to $\frac{13}{16}$″
Camber of standing ways	2′ 3″	1′ 0″	1′ 2″	1′ 0″	1′ 11″	1′ 10″	0′ 10″	1′ 0″	0′ 10″	0′ 8″	1′ 0″	0′ 6″
Length of standing ways { inner	345′	367′ 0″	395′ 0″	370′ 0″	348′ 0″	302′ 0″	300′ 0″	267′ 0″	250′ 0″	195′ 0″	259′ 0″	276′ 0″
Length of standing ways { outer	288′											
Length of sliding ways { inner	240′	284′ 0″	330′ 0″	305′ 0″	240′ 0″	206′ 0″	200′ 0″	180′ 0″	170′ 0″	150′ 0″	207′ 0″	190′ 0″
Length of sliding ways { outer	165′											
Breadth of sliding ways { inner	1′ 10″	1′ 9″	1′ 9″	1′ 9″	1′ 10″	1′ 8″	1′ 9″	1′ 9″	1′ 9″	1′ 3″	1′ 9″	1′ 9″
Breadth of sliding ways { outer	1′ 8″											
Area of sliding ways in square feet ...	1,430	994	1,155	1,067	880	666	700	630	595	375	725	665
Total fall in length of standing ways	23′ 0″	18′ 9″	19′ 7″	18′ 6″	21′ 6″	18′ 10″	15′ 6″	15′ 4″	14′ 6″	12′ 0″	15′ 0″	16′ 0″
Water on way ends	8′ 7″	6′ 0″	4′ 4″	2′ 6″	3′ 9″	3′ 10″	3′ 7″	2′ 8″	4′ 5″	2′ 9″	1′ 9″	2′ 0″
Draft of ship forward	11′ 2″	11′ 6″	7′ 0″	8′ 0¾″	6′ 6½″	6′ 0″	5′ 7″	5′ 9″	8′ 7″	4′ 0″	6′ 11″	9′ 2″
Draft of ship aft	16′ 6″	14′ 0″	10′ 10½″	10′ 5″	9′ 5½″	8′ 2″	10′ 8″	9′ 0″	7′ 1″	3′ 10″	9′ 11″	12′ 0″
Draft of ship, mean	13′ 10″	12′ 9″	9′ 0¾″	9′ 2⅞″	8′ 0″	7′ 1″	8′ 1½″	7′ 4½″	7′ 10″	3′ 11″	8′ 5″	10′ 7″
Displacement, in tons	2,850	2,500	2,157	2,240	1,660	1,100	1,000	865	700	215	1,015	1,750
Mean pressure per square foot on sliding ways, in tons	2·00	2·51	1·90	2·09	1·89	1·65	1·40	1·37	1·16	·57	1·40	2·63
Length of first period	278′ 0″	283′ 0″	250′ 6″	279′ 6″	237′ 6″	202′ 0″	249′ 0″	208′ 6″	190′ 0″	122′ 0″	212′ 0″	...
Length of second period	67′ 0″	84′ 0″	144′ 6″	90′ 6″	110′ 6″	100′ 0″	51′ 0″	58′ 6″	60′ 0″	73′ 0″	47′ 0″	...
Ratio of length of second period to length of sliding ways	28 %	30 %	44 %	30 %	46 %	50 %	25½ %	32½ %	35 %	49 %	23 %	...
Weight on sliding ways at commencement of second period, in tons ...	520	550	640	630	560	400	215	225	225	75	235	...
Weight on sliding ways at end of second period, in tons	250	290	300	380	255	125	110	115	115	25	170	...
Margin against tipping, in foot tons ..	10,500	33,250	80,000	35,300	53,500	39,000	5,400	9,700	12,300	5,500	...	...

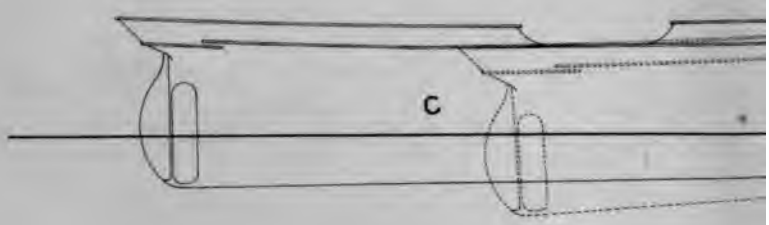
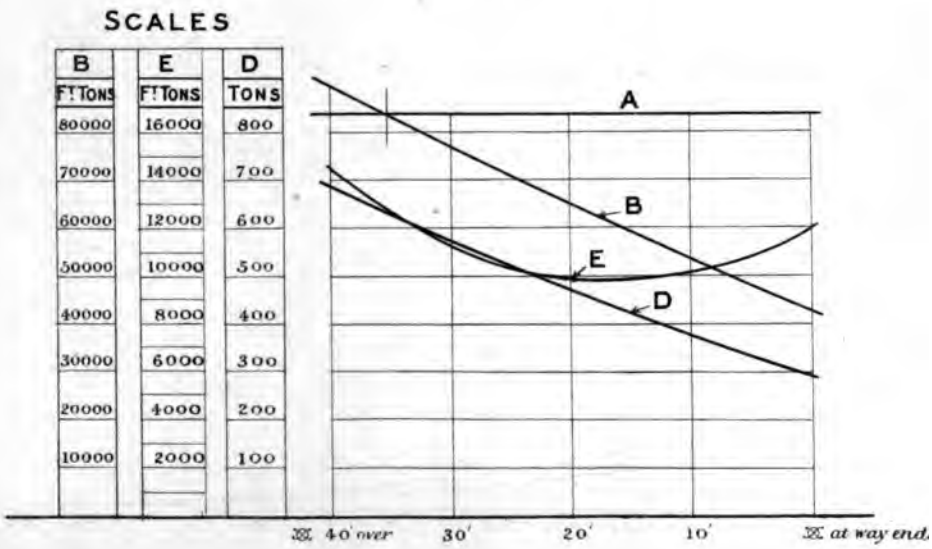
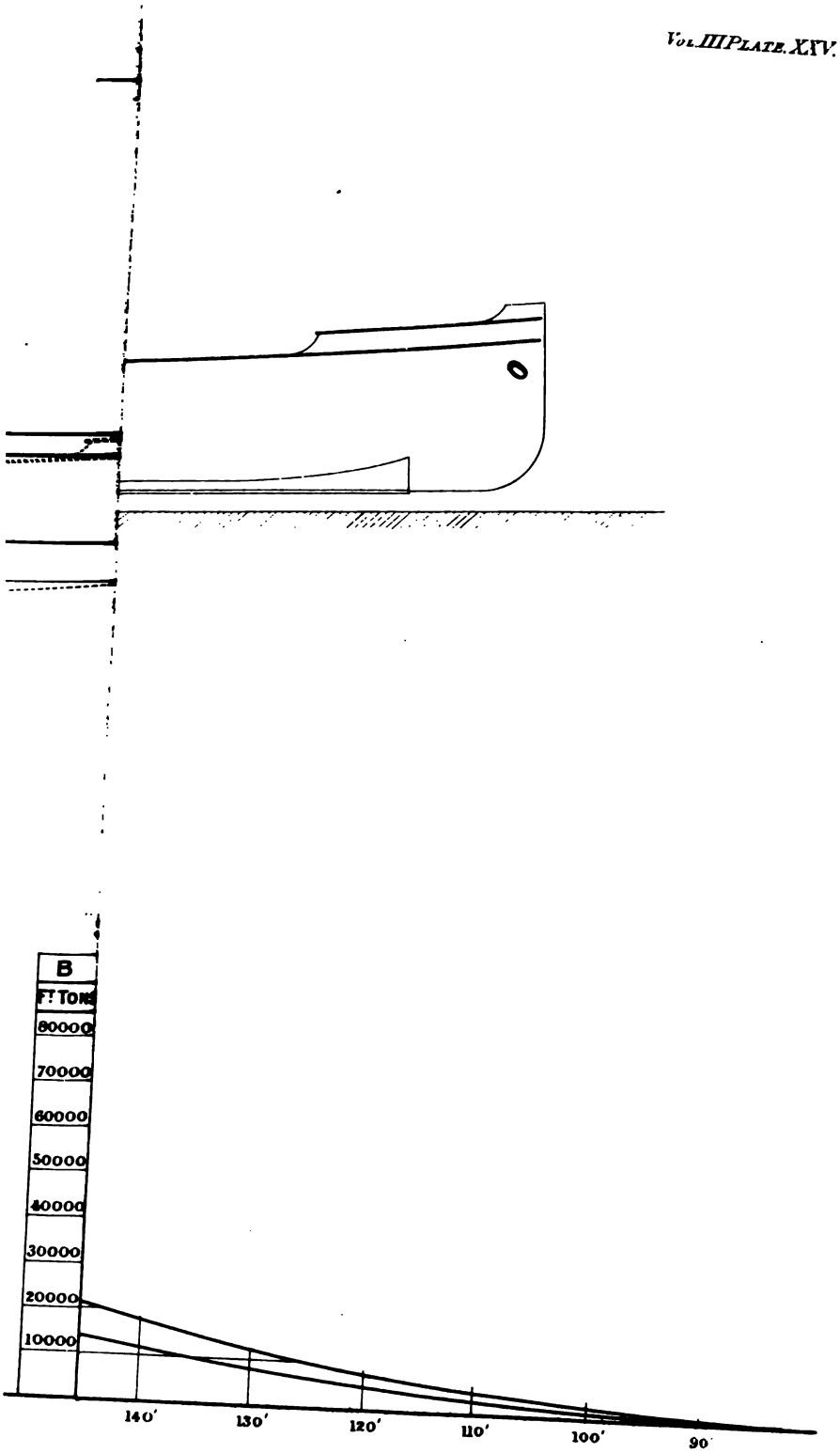

C

FIG. 3.

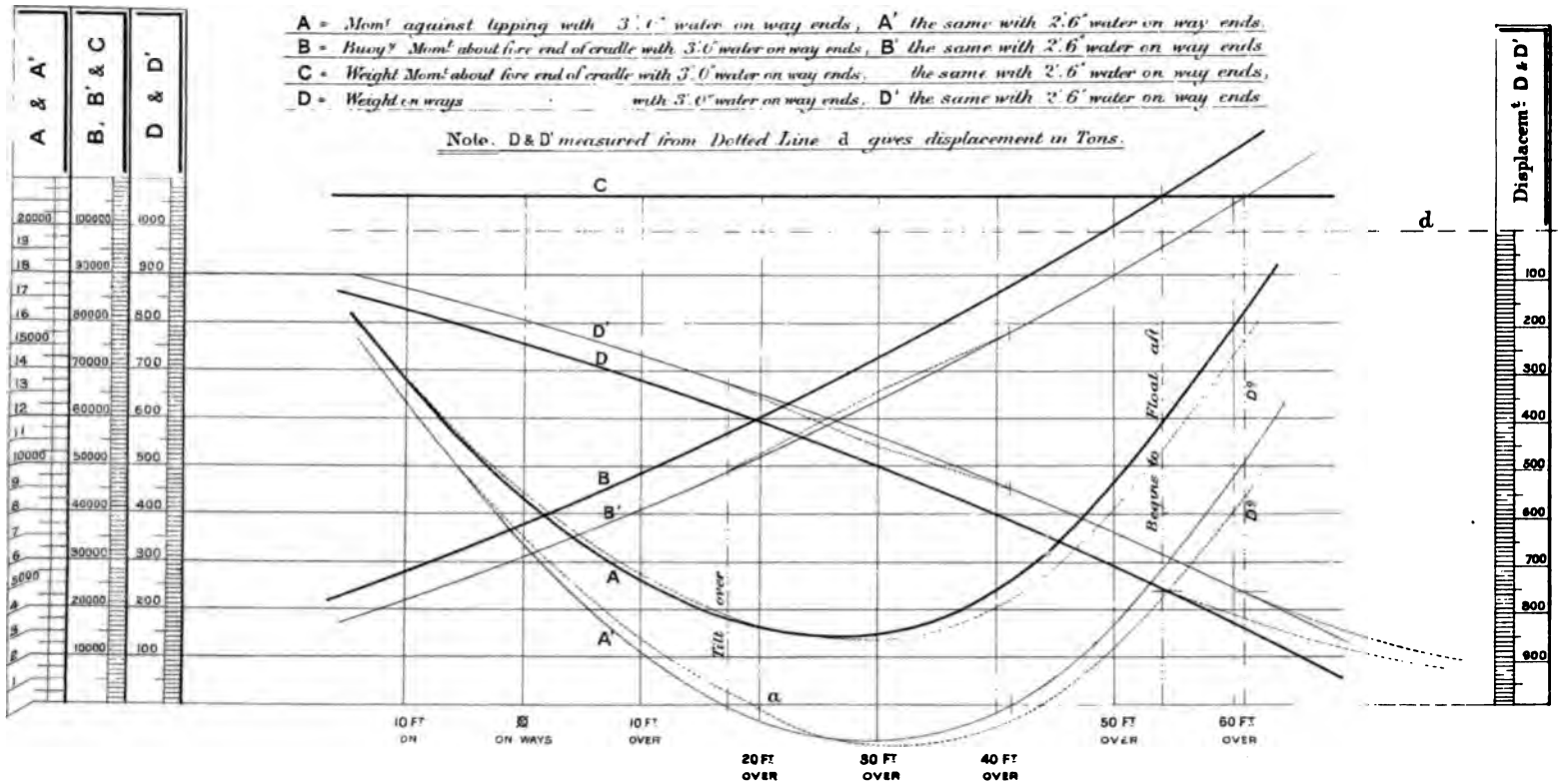

SCALES
B
Ft Tons
80000
70000
60000
50000
40000
30000
20000
10000
E
Ft Tons
16000
14000
12000
10000
8000
6000
4000
2000
D
Tons
800
700
600
500
400
300
200
100
A
B
E
D
℄ 40' over
30'
20'
10'
℄ at way end.



Art. Roy. Mil. Newcastle.

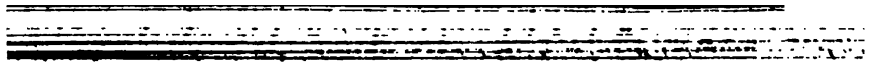
To illustrate Mr Gannaways paper on "Some Notes on the Launching of Vessels."

LAUNCHING DIAGRAM S.S."HAITAN" ALLUDED TO IN MR ULLSTRÖM'S SPEECH.


SCALES.
A & A'
B, B' & C
D & D'
A = Mom^t against tipping with 3'.0" water on way ends, A' the same with 2'.6" water on way ends.
B = Buoy^y Mom^t about fore end of cradle with 3'.0" water on way ends, B' the same with 2'.6" water on way ends
C = Weight Mom^t about fore end of cradle with 3'.0" water on way ends, the same with 2'.6" water on way ends,
D = Weight on ways with 3'.0" water on way ends, D' the same with 2'.6" water on way ends
Note. D & D' measured from Dotted Line d gives displacement in Tons.
Displacem^t D & D'
C
d
D'
D
B
B'
A
A'
Tilt over
Float aft
Beyond Fo
10 FT ON
ON WAYS
10 FT OVER
20 FT OVER
30 FT OVER
40 FT OVER
50 FT OVER
60 FT OVER

POSITION OF VESSEL ON WAYS.

Ann Reid, Lith. Newcastle.



favour of not tipping; in fact, in the case of one of them, had the water been only level with the way ends she would still have had sufficient buoyancy to prevent her tilting. The steamers G and H, which have each fine lines, the sailing vessel J, and the paddle steamer K, have all a very fair moment to prevent tipping, although not so large in proportion as the full cargo steamers. The steamer L is a very fine lined passenger vessel, and having very little water on the way ends for a vessel of this description, the weight moment did actually exceed the buoyancy moment; the excess however being very trifling, the tilting of the stern was scarcely perceptible and was not sufficient to do any harm.

For only the first two vessels (A and B) were calculations made to determine the form of the ways, the results of the launch in each case being successful, as shown by the table. With both of these cases it was certainly desirable to do so, as one vessel was a heavy war ship and the other was launched with all her machinery and masts on board. The calculations for the latter vessel showed that it was necessary to carry the ways considerably further out than was usually done for other large vessels built on the same slip.

From the data of the launches of the remainder of the vessels on the table, we are enabled to judge of the different results produced in launching without previously ascertaining if these results would be successful as far as the form of the ways and height of the water were concerned. It shows, then, that calculations are not necessary with most steamers of the ordinary sized cargo type, launched without machinery or ballast, as there is little fear of them tilting, which is seen by referring to the margins against tipping that the vessels marked on the table C, D, E, and F possessed, which vessels are all of this type. But vessels with fine lines, such as G, of course have not such large margins against tipping, and in the case of the vessel L, which is very similar to the one marked G, her stern actually did tilt as previously mentioned. In these vessels it is desirable in some cases to ascertain by calculation what would be the least amount of water that the vessel could be launched with, with any degree of safety, in case the tide on the proposed day of launching should fall short of what was expected.

In conclusion, the writer hopes he has impressed upon the members of this Institution the desirability of making launch diagrams before launching special types of vessels, in order that the length and declivity of the ways may be arranged, so as to give sufficient buoyancy to prevent tilting, and thus escape the possible dangers resulting therefrom.

The PRESIDENT said, as partly confirming the views expressed in the paper, he would give a few particulars of the launch of the large steamer which took place at his firm's yard yesterday; but unfortunately the time was too short since the launch to enable him to go as fully into the matter as he would like to have done. On page 150 the writer remarks—"The vessel's stern does not actually lift until she has moved a few feet beyond this point." According to calculation their vessel should have lifted when she was 50 feet over; instead of that it was 75 feet, that was 25 feet beyond the calculated point, which is about what the writer of the paper would expect. Referring to the question of tipping, the writer gave the tipping moment on the table as from 5,500 to 80,000. In their case they had, when the vessel was just on the point of tipping, 95,000; but 30 feet beyond that point it was reduced to 80,000. It struck him that the paper might have gone a good deal further into the question, although it was very interesting as it was. The writer said that the pressure on the sliding ways varied from $\frac{1}{2}$ a ton to $2\frac{1}{2}$ tons. If any of those were armour-clad vessels he should have expected them to have exceeded that weight very considerably, unless they were launched on double ways, and even then the actual weight would probably come on the two outer ways, and thus possibly exceed 5 tons per foot. In the case of their vessel yesterday it was 2·4, but they had launched vessels as far as 6 tons to the foot, and launched them safely.

Mr. ULLSTROM said, it afforded him great pleasure to be there that evening and to take part in the discussion of the very interesting paper they had just heard. With their permission he would now lay before them some diagrams of the S.S. "Haiten," a very fine and handsome steamer built by Messrs. Raylton Dixon & Co., of Middlesborough, for the Chinese passenger trade, and which was launched a few weeks ago. This vessel is 275 feet between perpendiculars and weighed at the time she was launched 995 tons. The ways (flat) were $14\frac{1}{2}$ inches wide, and had a declivity forward of $\frac{11}{16}$ of an inch per foot and $\frac{15}{16}$ of an inch per foot at the ends, with a camber of about 11 inches. The length of the cradle was 200 feet or ·727 of the length of vessel. The weight on the ways was thus 2·106 tons per square foot. The depth of water on way ends was 3 feet. As the launch was a most successful one, and, contrary to expectations, the vessel did not tip over, the speaker thought it would be of some interest to ascertain what kind of curves a launching diagram would give, he therefore calculated the diagram shown in Plate 26. It will be seen that the diagram is of the same kind as shown by Mr. Gannaway in Plate 25. A is the moment against tipping, B

buoyancy moment about fore end of cradle, C weight moment of vessel about the same place, and D weight on ways, which, of course, will be the weight of vessel minus the displacement. Looking at the curve A it will be seen that when the vessel arrives at the critical point—that is, when midship is 26′ 3″ over the way ends—there is a moment of 2,970 foot tons to prevent tipping. This margin no doubt appears small, but yet there was sufficient to keep the fore end of the vessel in the cradle. Again, looking at the curves marked B and C, both representing moments acting in opposition to each other, it will be found that the vessel begins to float aft when midship is 53 feet over the way ends, and that the weight on the fore end of cradle at that particular juncture, according to curve D, will be 245 tons. The displacement of cradle, in this calculation, has not been taken into consideration, but left out as a margin of safety. Now as the moment against tipping was so small, with 3 feet of water on the way ends he thought it would be rather interesting to see what effect 6 inches less water would have had, and thus he got out the fresh set of curves marked A', B', C', and D'. From curve A' it will be seen that the vessel will tilt over when midship gets 17′ 6″ over the way ends, and that the weight on the ways or pressure against the bottom of the vessel would be not less than 685 tons—no doubt a considerable pressure. The greatest deficiency of buoyancy moment will be when midships gets 30 feet over the way ends, or about 1,366 foot tons. Theoretically speaking this would tip the vessel about 3 inches by the stern, or lift the stem about 1½ inches; but practically it would be imperceptible, as it might reasonably be expected the ways would yield that much under the heavy pressure (685 tons) so suddenly concentrated on a somewhat limited space. This tipping would increase the buoyancy moment B' and decrease the weight on ways D', as shown by the dotted lines. The vessel would float aft when midship was 60′—6″ over the way ends (see intersection between B' and C') and throw a weight on the cradle forward of 245 tons, or the same as in the previous case. As the vessel, when reaching the point *a*, has a certain momentum due to her weight, and the speed at which she travels over the ways, the actual curves of moment against tipping would be something like the dotted lines shown on A and A'. With 2′ 6″ water on the way ends the tipping would then take place when midship had reached somewhere about the point *a'*. He would now ask Mr. Gannaway if he had made any observation with regard to this point, and if he could give any idea of the allowances that ought to be made. He had, as a matter more of interest than of any practical use, made out the pressure

against the dog-shores to be about 40 tons, and arrived at that by the formula—

$$P = \frac{W \sin \delta - f W \cos \delta}{\cos B},$$

where P = pressure on dog-shores,
W = weight of vessel,
δ = mean angle of declivity of ways under the vessel,
B = angle between ways and dog-shores,
and f = coefficient of friction expected to be between 1 and ·7.

He was sorry he had not had sufficient time to go more fully into the matter. He now wished to thank Mr. Gannaway very much for his interesting and able paper.

Mr. A. ADAMSON said, he was sure Mr. Gannaway deserved all their thanks for introducing the subject of launching vessels. He did not think it received the attention it deserved from a great many shipbuilders. He knew, from his own experience, that he always felt very much relieved when he saw any vessel launched safely into the water; at the same time, of the vessels he had seen launched, and which now numbered between four and five hundred, he could only remember three or four serious mishaps, and they, if he remembered rightly, were caused, as mentioned by Mr. Gannaway, either from tipping or from the vessel lifting aft and the weight coming on the fore end of the ways. He would like to ask the President if he was not in error in saying that they had launched vessels with as much weight as six tons to the foot on the ways, as that was exactly double of what was given by the best authorities?

The PRESIDENT said, he thought they might take that as correct.

Mr. ADAMSON, continuing, said, that in a very large merchant vessel, 500 feet long, whose launching weight was, if he remembered rightly, 4,600 tons, the weight per square foot on the cradle was about $2\frac{3}{4}$ tons, but, through some error on the part of the foreman shipwright, the ground ways were not a perfectly fair curve; they were laid to a camber, but which was not the same from top to bottom, therefore when the vessel moved down the ways the cradle did not fit the ground ways, and the whole weight of the vessel was thrown upon the middle of the cradle; this weight, as nearly as they could make out, somewhat exceeded three tons per foot, and was sufficient to bring the vessel to a standstill after she had run about 280 feet.

The PRESIDENT asked if that was owing to the wrong camber?

Mr. ADAMSON said he thought not; it was a very common practice, although entirely wrong, to increase the camber on the ways at the lower

end, and the ships, if there was not too much weight on the ways, got off, as a rule, all right. The case he mentioned, however, was an exceptional one altogether, the weight on the ways being so much to start with could not be increased without danger; the vessel was put off successfully two days afterwards with a weight of rather less than three tons. This increase over the original weight was owing to the bearing surface being less on account of the after length of the cradle being over the end of the ground ways when the vessel stopped. This had to be left out in relaying the ways. They were laid the second time without any camber, the upper surface being exactly a straight line. The cause of the stoppage was put down at the time to the unfair camber throwing too much weight on the middle of the ways. One of the other instances was the case of a war vessel through tipping. When the time for launching the ship arrived, it was found that there was a deficiency of about a foot in the water necessary for a safe launch; however, it was determined to go on, and the launch was beautiful. She went off apparently all right and very quickly, there was no sign of tipping; however, when the ship was examined inside it was found that three or four longitudinals were cracked, showing that the vessel must have got a nip in coming off the ways. The damage was not very serious as the outside skin was not injured. If this vessel had not gone off so quickly probably the injury would have been much more serious. Another instance that he remembered, and these were the only three accidents that were of any consequence, was from the opposite cause, the lifting of the stern. It was in the case of a steamer for river service in China, 300 feet long, 50 feet beam, and very shallow, drawing only 5 feet of water. When she was launched there was too much water; she lifted aft and cracked two or three frames, they were under water and it was not noticed; it was, however, curiously enough, one of the principal causes of that ship being wrecked. She had her engines fitted in, and was to steam out to China. When she got to the south of Ireland it was rather heavy weather. The captain and officers became alarmed at the working of the vessel, and went down to the fore hold, where they saw the cracked frames, and the shell dented in one or two inches; they thought the ship was going to pieces, so they put back for the Clyde, and encountering a terrific storm, were wrecked at the entrance to Ardrossan Harbour. These were almost the only instances of mischance at launches which had come under his observation; perhaps some of the other members could add to the list.

The PRESIDENT asked if the large vessel which Mr. Adamson had referred to was launched with flat or hollow ways?

Mr. ADAMSON said, they were all flat ways. In connection with the weight per foot, Mr. Adamson said, he might mention that with the exception of the very large vessel all the other weights were under $2\frac{3}{4}$ tons. He had never heard of an ironclad being launched with anything approaching 3 tons on either double or single ways. If there was not sufficient surface on the single ways, another could be laid alongside to reduce the weight per foot.

Mr. MACOLL said, they had had a very interesting paper on a very interesting subject, and one, like most subjects connected with ships, which was capable of being considered in a variety of ways. From the time the vessel started until she was in the water she was to all intents and purposes a falling body; and the problem was, to let her fall gently into the water, being safely land-borne until she was safely water-borne, and after getting afloat, to be brought up. Each district had its own way of working. In one district they found all flat ways, and in another all round or hollow ways. When with hollow ways a larger carrying surface was wanted an additional number of ways was added, so as to increase the bearing surface, while with flat ways it was simply a question of adding more width, and it was usually reckoned safer to launch only on one pair of ways. Most large vessels, ironclads and others, built in Government yards were launched on flat ways, and they had very few mishaps with them; but there was one matter to which they required to give attention, and that was a great deal of internal strutting and stiffening in the line of the ways. The shell plating by itself was too weak to carry the weight concentrated on the ways in launching, and it was quite usual to fit struts, chocks, or shores from the shell to the inner bottom, and then continue and distribute the strain to a strong deck above by shores. He knew of two or three cases of long vessels being indented at the fore end of the ways, the shell plating not being able to sustain the strain brought on the fore end by the vessel getting afloat and lifting aft. In one case the ways had been fitted some weeks before the date of launch, and shortly before launching were taken out to be greased, and while being fitted in again, by some means the fore poppets or shores got off the frames, resting only on the plating, with the result that at the fore end of the ways the plating was indented for several feet in the way of the shores. No appearance of damage was observed at the time, and it was only after the vessel was docked the damage was discovered. As to the remark of the writer of the paper to the effect that if the tide was high there was a greater weight thrown on the fore part of the ways, he did not quite see that it made any material difference on the total weight carried by the

fore half of the ways. Certainly, a greater depth of water on the way ends would bring the weight sooner on the fore end, and would intensify the weight on the extreme fore end just before dipping, but he did not think the actual or gross weight forward was much altered. Another question which occurred to him was the effect on the stability of a launching vessel having the fore peak full of water, especially when associated with great depth in proportion to beam, and possibly a large amount of top-hamper on deck. The centre of gravity of the water in the fore peak tank would likely be considerably above the centre of gravity of the hull, and it might happen the ways would come out on the one side of the vessel, and so give her a list, and this could easily be exaggerated by the checks used for stopping the vessel's way. Another matter was bad tallow, which had been instrumental in causing some unsuccessful launches. As to the weight per foot, he might say the greatest he had personal knowledge of was fully 4 tons. The vessel was launched with engines and boilers on board. The result was by no means encouraging, and certainly indicated the necessity of having considerably less weight, or *per contra* more surface of ways.

Mr. STIRZAKER expressed himself greatly pleased that the necessity of calculation had been urged upon them with regard to the launching of ships. It was only of late years that any kind of calculation was considered of consequence by the majority of shipbuilders. He observed that the paper treated of only one feature of ship launching, namely, the tendency of the ship to tip as she leaves the ways. He thought it would have been instructive if Mr. Gannaway had touched upon some other points, such as the amount of energy required to cause a vessel to take the water, and the various methods of absorbing the surplus energy developed by the launching of heavy ships, such as armour-clads. He had seen a small ship launched from a famous shipbuilding yard, where only the largest class of vessels was usually built, brought up by the resistance of the water before she was half off the ways, because the energy stored up in her was not sufficient to carry her in. This proved, that even in that yard, the "rule of thumb" was largely worked to.

Mr. T. MILLAR said, he should have liked very much if some of the older members connected with shipbuilding had given them the benefit of their experience in the launching of vessels. He thought Mr. Gannaway deserved their warmest thanks for bringing such an interesting subject before them. Although it was not necessary to work out calculations and make diagrams for the launching of every vessel, still the working out of these calculutions, etc., ought to be looked upon as ordinary office

work, which might have to be taken up at any time. After the very clear and able way in which Mr. Gannaway had explained the method of getting out particulars for laying off the necessary diagrams, he had no doubt some of the younger members would feel interested enough in the matter to go into it fully. Mr. Shepherd, a member of the Institution of Naval Architects, who read a very interesting paper before that society in 1877 on the launching of ships, outlined the method which had been fully explained to them that night. One or two of the speakers found fault with the author for not making his paper a little longer and going more fully into the subject of launching, but he stated at the beginning of his paper that "his main object was to deal with the form of launching ways," and he thought he acted wisely in only dealing with one part of a subject, which had not, and even yet did not, receive that full consideration which was its due. No doubt as years went on it would receive the attention it deserved. Very few papers had been written on that very interesting subject, he could only find record of three having been read before the members of the Institution of Naval Architects bearing directly on the launching of ships. One was the paper already referred to, and there were one or two points brought out in that paper which, if not fully considered, would upset the most careful calculations which could be made. There was the nature of the ground to take into account, so that there would be no danger of it giving way when the full weight of the vessel came on the launching ways after the keel blocks were knocked out—the weight which ordinary ground would bear being 1 to 1½ tons, and good ground 2 to 2½ tons. One of the reasons for cambering the ways was to make allowance for any sinking which might take place in the ground during the passage of the vessel to the water. Regarding the weight per square foot on the sliding ways, the highest record he could find was of a war vessel which was a little over 3 tons. In general practice, and in the majority of shipbuilding yards, he did not think that it was very much over 2½ tons per square foot. He was surprised when the President informed them he had ventured as far as 6 tons per square foot. He should liked to have seen a sample of the tallow used, and know what time of the year the launch took place. He quite agreed with the author of the paper that the duration of the second period should be made as short as possible, thereby decreasing the velocity of the vessel on leaving the ways, and lessening the strain thrown upon the checking chains and anchors, a most important consideration in launching in rivers such as the Tyne and Wear, where the run is limited. The weight thrown on the cradle during the second period was very easily

arrived at, and could be allowed for in the making up. One of the previous speakers mentioned about a vessel having been indented by the pressure of the forward ways on the bows. No doubt that would have been prevented by shoring had there been any reason to suppose there was danger of that taking place. Mr. Macoll spoke about the effect which filling the fore peak tank would have on the stability. He did not think that it had any effect beyond shifting the centre of gravity of the whole weight forward, and so increasing the positive tipping moments. The writer of the paper showed very clearly the effect which lengthening or shortening the ways and increasing or reducing the camber had on the tipping moments. It would be interesting to know the proper percentage which the ratio of the length of the second period should bear to the length of the sliding ways.

Mr. SANDISON said, as they were on the Wear that night, perhaps some of the local shipbuilders would give their experience with broadside launching. It was a subject which Mr. Gannaway had not touched upon, and he understood it was somewhat in vogue on that river.

The PRESIDENT said, in reply to a previous speaker, the four ships which he referred to were all launched in the winter months. He did not think there was much tallow left, for the ways were partly burnt; however, they were launched and launched safely.

Mr. GANNAWAY in reply said, that regarding the President's remarks about the point where the stern commences to lift, he had found that vessels travelled about 10 to 20 feet, according to size, beyond the point where buoyancy and weight moments were both equal before their sterns commenced to lift. This distance in the vessel A on the table (page 154) was 12 feet, and in the vessel B 18 feet. The distance of 25 feet travelled by the vessel alluded to by the President does not appear out of the way considering her great length. The minimum moment against tipping of 80,000 foot-tons in the same vessel is exactly the amount possessed by the vessel C in the table, which vessel is of a similar type, although not quite so large. The only armoured vessel on the table is the one marked A, which vessel was launched on double ways, the weight per square foot on the ways being exactly 2 tons. He had heard of a weight of 3 tons per square foot in the case of large ironclads, but had not heard of anything so high as 6 tons before. The launch diagram prepared by Mr. Ullstrom shows that this vessel had only just enough water over the ways to prevent tipping. It is not an unusual thing for vessels to tip slightly when leaving the ways, and as the tipping moment is generally very small, no harm results from it. The damage received by the war

vessel referred to by Mr. Adamson is an example, however, of the risk run in allowing heavy vessels to tilt. He had never made any observations with regard to the actual tipping point referred to by Mr. Ullstrom. Mr. Adamson in his remarks gave us an account of all the mishaps that had occurred in the great number of launches that he had witnessed, and, it is singular to note, that each of these mishaps were attributed either to the form of the ways or the height of the water. In one case there was not enough water, in another there was too much, and in the third vessel the ways did not form a true arc of a circle. In reply to Mr. Macoll's remarks about the weight at the fore end of the sliding ways at the beginning of the second period, this weight does remain about the same with any depth of water over the way ends with the same form of ways; but with a certain depth of water, if the second period is lengthened by means of increasing the camber of the ways, then both the length of this period and also the weight at the fore end of the sliding ways at the commencement of the same period are increased. For an example, take the vessel on Plate 25, Fig. 1. By increasing the camber of the ways from 12 to 18 inches, the length of the second period is increased from 32½ per cent. to 40 per cent. of the length of the sliding ways, and the weight at the fore end of the sliding ways increased from 225 to 250 tons. As to the effect on the stability of a vessel by filling the fore peak with water, in order to decrease the weight moment about the fore end of the sliding ways, the paper does not refer to water ballast in the fore peak, but says ballast may be put into the fore end of the vessel. In the case of the vessel M on the table, which is referred to in the paper, the filling of her fore peak with water would not have made any perceptible difference in her stability. Regarding the proper ratio of length of second period to length of sliding ways, referred to by Mr. Millar, the smaller this is the better. It cannot, however, be got any lower than about 25 per cent. without the vessel tipping.

The PRESIDENT said, evidently from the way in which the paper had been received, it was a subject that would bear a good deal of writing about yet, and he hoped by next session they would have another paper on the same subject. At present they knew very little about it scientifically, and undoubtedly often unwittingly ran very near the extreme margin of safety. He had great pleasure in proposing a hearty vote of thanks to Mr. Gannaway for his very interesting paper.

This was carried by acclamation.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886–87.

PROCEEDINGS.

THE following paper was written by the late Mr. IVAN MAVOR, who was killed in the explosion on board the petroleum steamer "Petriana," at Birkenhead, December 26th, 1886, and was intended to have been read by him at the January meeting of the Institution; but, owing to his lamentable and untimely death, no meeting was held, and it was decided, as a tribute to his memory, that the paper should be printed and issued to members as part of the Transactions of the Institution.

TECHNICAL EDUCATION FOR ENGINEERS AND SHIPBUILDERS.

By Mr. IVAN MAVOR.

A GENERATION ago Britain stood almost alone among the nations as a mechanical workshop and supplied nearly the whole world with machinery. Now conditions are much changed, competition is much keener, the requirements from mechanical men are more excessive, and the time given for production is shorter. We are being closely pressed in competition by our neighbours, who were formerly our customers, and who are competing in our own markets at home and in the colonies.

To retain our position we must be ever on the alert to grasp the changes continually taking place in the world's requirements, to take advantage of all the progress made in art and science, to keep our work ahead of that of our neighbours, and to produce cheaper and better manufactures. The most potent assistance towards this end is to have extended educational facilities for all engaged in mechanical pursuits.

This has been so far agreed upon by engineers that it is useless to advance arguments here in favour of extended technical education, including under this title all the specific instruction required by those being trained for mechanical work.

For a complete training in shipbuilding or engineering it is essential that workshop practice go hand in hand with instruction in the principles which govern the practical work.

Let it be clearly understood, however, that the teaching of the principles must always be auxiliary to the learning of a trade or craft by active work. It has always been the order of progress that art goes first and afterwards science; and it may safely be laid down that it is necessary first to ground in practice and then the study of the science becomes not only easier but infinitely more interesting and instructive.

In order that industry may derive the fullest benefit from an educational system this latter must be available to all who are able and willing

to work for it. But to reach the most perfect organization it would seem that the educational system must be arranged primarily for apprentices, the education of others being subsidiary to this consideration. Let it, however, be fully recognised that facilities should also be afforded to those who have passed out of their apprenticeship, otherwise we would in a few years have the more experienced men crowded out by youths who had had superior advantages, a condition manifestly unfair.

Under existing conditions the manner in which most apprentices learn their business invariably depends upon themselves, and in many establishments the conditions are very much against their ever acquiring a knowledge such as will fit them to earn their living. This applies almost equally to those who enter the shops and those who enter the drawing offices. In some places such a thing as an apprentice passing from the yard or shop to the drawing office is almost unknown, and in many places such a thing has never occurred. Youths entering most drawing offices spend several years doing office drudgery. These are some of the most valuable years in their lives, as they immediately succeed the period of school education and are at the time when a boy ought to have his faculties quickened by finding some application for his earlier training. As it is the right chord in many cases is never struck, the sympathies are not awakened till years have passed and interests and habits have been formed which must be broken down before a real training is begun—surely no fit beginning for those who are to carry on the greatest of our national industries in a generation during which conditions will have become more rigorous than now, and in which more will be required of mechanicians than has ever been called for in the past.

What applies to drawing office work applies also, though in a less degree, to the work of the shops.

It has been over and over again contended that we must establish technical schools at which our artizans can be taught handicraft. This has been done with great success on the Continent, where much benefit has accrued to some trades, such as wood carving, gilding, and engraving, from the instruction given in technical schools; but in these arts one can do nothing in production till a certain amount of handicraft is learnt, and all the work depends upon the skill with which certain instruments are manipulated, and this manipulation cannot be satisfactorily taught under the conditions which hold in workshops.

In engineering and shipbuilding there seems, however, no good reason for taking out of the workshop this, the most important part of technical training. Since its development aims at the improvement of production,

students should always be in contact with actual production for commercial purposes, and where all the workmen are made to feel the pressure of outside competition.

Proposals have been made at several colleges (I don't know in how many they have been carried out) to make machines for sale. This seems a most impractical idea, and it is highly improbable that machines produced in this way could ever take a place in the market beside others manufactured in the regular way in large numbers. If they cannot be produced in colleges at marketable prices the attempt will end in a tendency towards playing at engineering.

It is not claimed that the existing condition of apprentices in large shops is perfect. Much more might be done to put information in the way of youths, and more care should be taken that they have facilities for learning. In this connection the late Professor Fleeming Jenkin made a most sensible proposal. It was to have in every workshop a mechanic of superior skill, whose duty it would be to take charge of the instruction of apprentices, and to teach them how to make, sharpen, and use their tools. The present system generally adopted of setting one apprentice to work with a journeyman is often most unsatisfactory, and the deputing to one man that which is now too often the duty of every one would undoubtedly tend to the improvement of our handicraft and would probably repay the outlay by raising the standard of the boys' work.

But it is to schools and colleges that we must look for the means of imparting that knowledge of principles essential for the successful carrying on of mechanical work. It has always been a very vexed question as to how far in this direction we should attempt to go in teaching artizans. Let this answer be hazarded—that they should be taught just as much as they are capable of absorbing. No man will do his work less satisfactorily because he knows the reasons for certain steps being taken and certain processes being adopted. It appears that only prejudice would cause obstacles to be put in the way of a man's acquiring all the knowledge possible of the results of scientific research. Facilities for acquiring such knowledge would bring out the best ability, much of which is now occupied with pursuits altogether foreign to every-day avocations, and would reflect favourably upon the mental, moral, and social condition of our artizan classes.

It is the continual complaint of teachers that their students are not sufficiently prepared to receive instruction in pure science; and to remedy as far as possible this very serious defect, apprentices should attend classes as soon as they start upon their career, so that no time may be lost

during which they would otherwise forget all their school training. It is not too much to say that at present one-half of our apprentices could not, after the lapse of two years, pass their last school-standard examination.

These classes for beginning upon the course of technical study should be held at all the local centres of industry, and might be arranged for such subjects as the higher rules of arithmetic, elementary mathematics, mechanics, practical plane and solid geometry, with applications to the lining off and setting out of work. These classes could be common to engineers and shipbuilders, and advantage would accrue to both from having some part of their instruction carried on together. This should apply, as far as possible, to all their subsequent training; for shipbuilders are all the better for having a little engineering associated with their work, and let us hope that engineers would at least be none the worse for being in close contact with shipbuilders. The course of instruction at the elementary schools includes much that is taught in public schools; but it will be in the experience of most who have had to deal with youths from school, that they are almost always incapable of applying the knowledge they possess, and in order to give them a grasp of the subjects they must be taught by trained mechanics, who know the direction to give to the work so that it may be of the greatest practical benefit. Many lads would pass rapidly through this stage by reason of superior school education, and many, on the other hand, would never get beyond this stage. It seems desirable, however, that all should pass through the same work to ensure their thorough preparedness for the more advanced study to follow.

The natural step from the preparatory local schools would be to a central school or college, where instruction would be continued in the direct lines of the requirements for the various trades.

In order to exercise as fully as possible the true function of education a very great deal of time must be spent in home work, and no arrangement will obviate the necessity for burning the midnight oil by those who would acquire a thorough knowledge of the two finest of human arts.

That home work may be done satisfactorily every evening in the week must be occupied. This brings us to one of two conclusions, viz., either that the classes in the central school be taught during the day, or during some afternoons. The first arrangement does not appeal to the practical mind as the best, since it puts a stop, for a time at least, to shopwork; for, besides the financial question, this is against what was claimed at first as an essential feature of technical training, viz., that the

student should not at any time be out of touch with the competition of production. The second plan would be to allow students at the secondary school to go on at least one afternoon every week to school. This is not so radical a proposal as it may seem, for in all the royal dockyards the apprentices spend two afternoons a week in school. It is of course intended that only those who had satisfactorily passed out of the elementary schools should be granted the privilege of leaving work on part of a day for the purpose, this being a reward for diligent and successful work.

It is not pretended that educational facilities will make geniuses of all; on the contrary it is likely that a large number would never get beyond the first stages, and attendance of classes by many of these would be a waste of time.

The classes could be so arranged that there would be only one-third or one-fourth of the college students absent from one shop, making a proportion of one-eighth or one-tenth of all the apprentices absent at a time. The proposal may be open to some objections, but from every point of view it seems to be the only practical way of meeting the difficulty now experienced in getting full and complete home work done by the students of science classes.

The instruction would then proceed in continuation of the work of the preparatory schools, showing further applications of geometry to ordinary work, the principles of construction, and the strengths of the simpler structures, with the rules for dealing with volumes, etc., the rules of calculation being given without proof, which would come afterwards when a more extended knowledge of pure mathematics had been acquired. To those who desired it, classes should be available for more advanced mathematics; but attendance at these should not be by any means compulsory, and as much as possible of pure and applied mechanics should be taught, without the use of algebra beyond simple equations, or trigonometry beyond the solution of triangles, and certainly all the rules for dealing with strains and with mensuration could be taught without going deeper into pure mathematics. It is not intended to deprecate the study of the only science which has ever been called "pure," and which supplies a mental discipline which no other study can give; but it is well known that many strong, practical, and useful minds are incapable of solving mathematical reasoning, and they should not on this account be denied the advantage of all the training which can be got without it.

Although not compulsory, the study of pure mathematics should be encouraged to the very fullest extent, so that students may pass on to the more difficult subjects connected with design.

Contemporaneously with this more abstract work, classes should be arranged for the study of the properties and strength of materials used in engineering and shipbuilding. These classes should be held in the evening, and be made available to all artizans as well as to those who had not succeeded in passing to the college classes from the elementary schools. The course might include the description of the properties of all the metals and timber used in construction, and illustrated as fully as possible by tests and microscopical examination.

Following upon this ground work should come the study of structures, full prominence being given to the most practical points. Here the engineers and shipbuilders would divide the applications bearing upon their different branches; and this study should include the careful consideration of all the machine tools used for working wood and iron, the principles of the various machines being studied with great care, for it is here we must look in the near future for the reduction of the cost of production by the further application of power to the work of the shipyard. The study of design would follow, and those who had so far passed through the course successfully would be taught the principles of design and be made to work out examples at the college.

Here care must be exercised in laying out the work, because of the very short time spent at school and the length of time required to draw out one design; but several students might take part in the preparation of each, so that time would be saved and a greater amount of work gone through. This part of the course could be made most interesting to shipbuilders by the preparation of standard designs of several of the best known types of vessels for all purposes. The calculations of the properties of the vessel being carried on while the design is in progress.

In order that such a course of study may be adequately taken advantage of impetus is necessary. This impetus must be supplied by employers. Apprentices could have endorsed on their indentures a list of the classes attended. Drawing office staffs should be recruited from the ranks of those who have successfully passed through the work of the classes.

Present drawing office training is woefully deficient. It is a common thing to hear engineering and shipbuilding dignified with the title of professions; but they are unlike most professions, inasmuch as anyone may walk through a certain routine and after a few years call himself an "Engineer." There is no fear of everyone becoming too highly educated. There will always be a very large number who prefer enjoyment to constant application, and who do not choose to "spurn delights

and lead laborious days." What we want are facilities for those who are anxious to learn their business; and to secure these, employers must be prepared to show considerable elasticity.

Having sketched what seems to be a desirable course of study, let us look around and see how far our present facilities go towards meeting the necessities of the case.

We have not, in this country (outside of the Public Service), the means of regular and systematic instruction in engineering and shipbuilding. There are a host of classes doing excellent elementary work in connection with the Science and Art Department; but, from the conditions under which these classes are conducted, it is impossible to do more than touch on the very fringe of the subjects taught, and as the work is all done in the evenings, complete education in the higher branches is out of the question.

A chair of Naval Architecture and Marine Engineering has been founded at Glasgow University, and will doubtless do good work, but has not yet had time enough to show much result.

There is an advanced school of the very highest order at the Royal Naval College, Greenwich, but it has never had the support from outside the Admiralty that its importance would lead one to expect. The causes for this are not far to seek. The course extends over three years, during which almost no other work can be done. To benefit by the instruction given a thorough knowledge of mathematics is necessary. The cost of the classes and of living in London puts it quite beyond the means of most of those who adopt engineering or shipbuilding as a means of livelihood. Three years is much too long for a youth to spend away from practical work at such an age as is reached before the necessary mathematical knowledge is acquired.

At present there are no schools in the provinces in which a preparatory training can be got similar to that received by dockyard apprentices before going to Greenwich. And it is only at a university that this work can be done, thus involving still further absence from practical work and consequent sacrifice of experience. Efforts have been made to induce private students to come forward for the course at Greenwich; and, to make it more accessible, free studentships with bursaries attached, have been offered for the last ten years. Although these have been competed for they have never yet been awarded, and the instruction is reserved for those who can afford to pay for it. Much good might be derived by private establishments from the excellent instruction given at Greenwich if several students were prepared annually in the provinces to proceed to

the Royal Naval College, where instruction in war vessel design can be got better than anywhere else in the world. It might be arranged that these candidates should do the work of the first two years before going, and be prepared for the study of design, so as to make the period of residence away from work one year instead of three.

It seems then, that there is a necessity for secondary training colleges open to all capable of receiving a scientific training. These colleges should be at the industrial centres, right in the heart of the busiest quarters. The students and teachers would be brought into intimate contact with production on a large scale. The benefit to the teachers would not be less than to the students; they would be continually reminded that their students were being brought up to practise their science and art for commercial purposes—a very essential feature apt to be lost sight of by those entrusted with education.

A college thus located would have a much better chance of attracting students from abroad, since the training would be much more complete than could be obtained under other conditions.

For the satisfactory carrying out of this idea of advanced education very great care must be exercised in determining the equipment of the colleges. In this as in other points, as to the course of study and so on, counsel and assistance should be sought from practical men who have felt the want of educational facilities, and who know best the lines on which instruction should proceed to be of the greatest benefit. The college should possess, besides the usual lecture rooms, a laboratory with a testing machine of the most modern construction, with which experiments on the properties of materials could be carried out. There should also be at least one experimental steam engine with boiler. A large room should be fitted up as a drawing class room, in which designs could be worked out by the senior students. In this room there should be block models of as many typical ships and as many drawings of engines and machines as can be got so as to give clear ideas of the varieties of form and class.

For lecturing purposes there should be sectional models of the various systems of construction carried on here and on the Continent. Machine makers could furnish drawings or models of all the principal power tools in use in the ships and yards. This is a subject to which sufficient prominence has not yet been given. It is of the utmost importance that the features and capacity of all machine tools should be thoroughly well known by those who are being trained as engineers and shipbuilders.

The college library should contain all the books published on marine

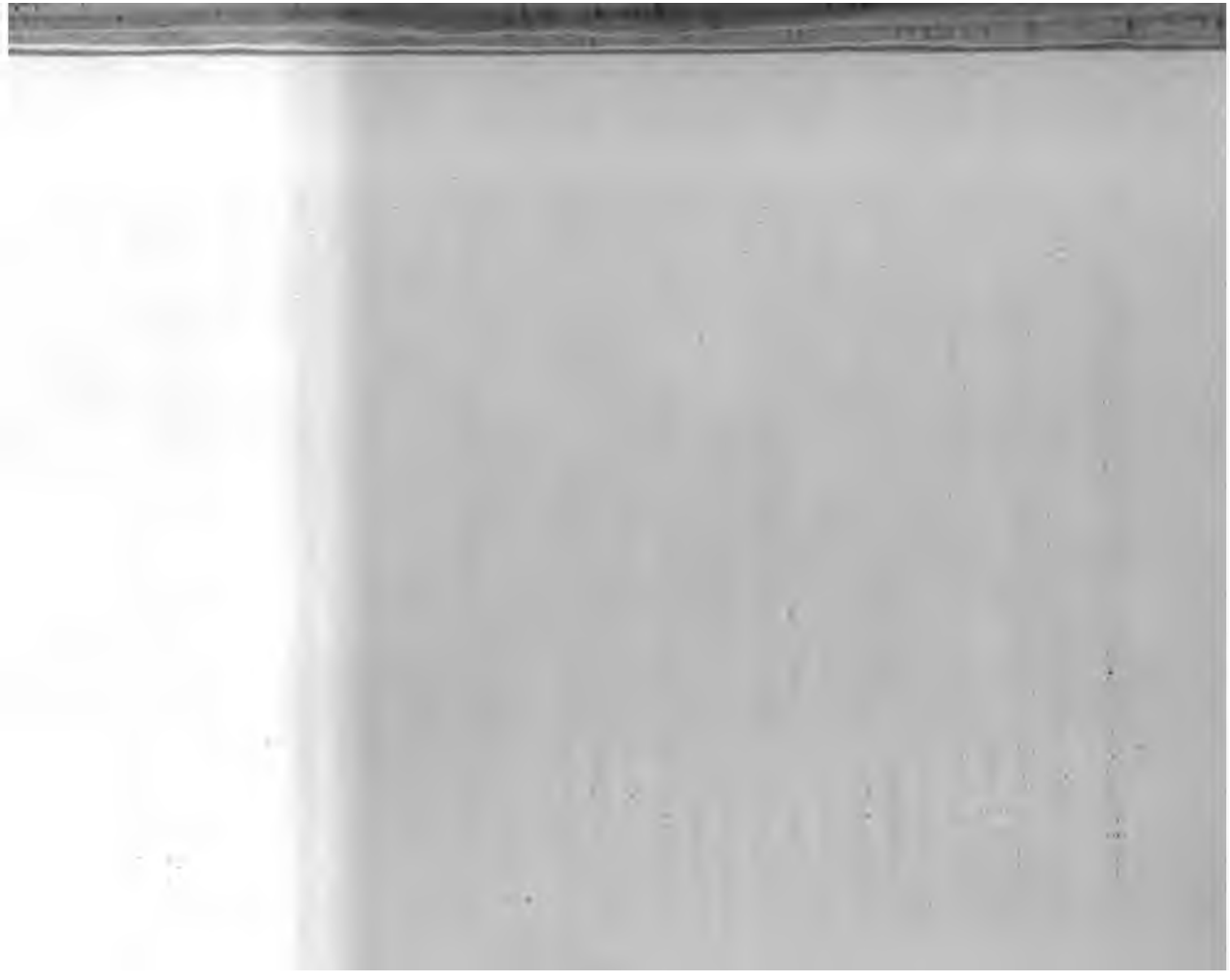
engineering and shipbuilding in our own language as well as in French, German, and Italian, the papers of all the scientific societies, and the mechanical journals.

Before leaving the subject something must be said about the financial aspect of the question.

It has already been insisted that the class fees must be such that none will be excluded on the score of poverty. To get all the assistance possible from the Science and Art Department their grants should be taken advantage of to the fullest extent, and those students not prepared to attend regularly and sit for examination should be required to pay in addition to the ordinary fee a sum equal to the grant.

To establish a college in such a district as this (the North-East Coast of England) a large sum of money should be subscribed for building and equipment, and to endow at least one chair. If it be once recognised, however, that there is need for such an institution, we are in a part of the world where the matter will not be allowed to rest until the want is met.

There is a very general desire here to put this district in the front rank of mechanical industry. There is no surer means of raising the tone of the locality than by spreading education; and employers must show considerable flexibility, and be prepared to encourage all in their service to take advantage of the benefits to be derived from the college work. This is more necessary now than ever before. We are passing into an era in which the requirements from mechanicians will be infinitely more rigorous than in the past, the division of labour producing more specialism. Life is harder, faster, and no doubt shorter, leaving less time for acquiring knowledge and calling earlier for its application. Let us then not be found lagging in the race, but doing at least all that our neighbours are doing for advancement.



NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886–87.

PROCEEDINGS.

SIXTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON WEDNESDAY EVENING, MARCH 9TH, 1887.

W. THEO. DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the last general meeting, held in Sunderland, on February 9th, which were approved by the members present, and signed by the President.

The ballot for new members having been taken, the President appointed Messrs. H. Charlton and C. W. Hutchinson to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Berkley, Alfred Benson, Grange Villa, Jarrow.
Bray, C. H., 9, Frederick Street, Sunderland.
Dacres, Thomas H., 14, De Grey Street, Newcastle.
Evans, Henry A., 16, Windsor Terrace, Gateshead.
Hymers, Richard, 197, Norfolk Road, Byker, Newcastle.
Marshall, R. J., 32, Mariners' Cottages, South Shields.
Martens, D., 52, Kent Street, Jarrow.
Maughan, William, 15, Addison Road, Heaton.
Messenger, Thomas, 2, Clarence Lawn, Dover, Kent.
Ramsay, William George, 10, Stanhope Road, Tyne Dock.
Reed, Thomas A., 1, St. John's Terrace, Jarrow.
Rendel, L. J., 61, Westmorland Road, Newcastle.
Sheppard, W. O., Pottery Lane, Newcastle.
Turner, Sam. Jopling, 86, Addison Road, Heaton.

ASSOCIATE.

Varley, John, 131, Hyde Park Road, Leeds.

GRADUATES.

Brackenbury, H. J., 2, Campbell Street, Newcastle.
French, James, 7, Avenue, Wallsend-on-Tyne.

The PRESIDENT said, it was his unfortunate duty to have to announce the loss of another member of the Council, Mr. John Brockat, who had been a member of the Institution from its formation, and he was sure his loss would be felt by all those who personally knew him. They would remember that at the General Meeting, held on February 3rd, a resolution was moved by Mr. Stirzaker, and carried, asking the Council of the Institution to consider the question of the accident on board of the S.S. "Petriana." The Council had considered the matter very fully, and had come to the following resolution, viz.:—"The Council having considered Mr. Stirzaker's motion, is of opinion that although the verdict is far from satisfactory, and does not appear to be in accordance with the facts of the case, the Council does not see its way to re-open the enquiry with beneficial results." He might say that it was with great hesitation the Council passed that resolution, for although the Council unanimously felt that the enquiry was not satisfactory, yet it could not see its way to do anything further in the matter. The Council had had under consideration the advisability of inviting the Institution of Naval Architects to visit the North-East Coast this summer. This matter was fully considered, and a resolution passed authorising him, as their President, to send an invitation through Lord Ravensworth, which he hoped would meet with their (the members) approval. He might say there would be some considerable cost in connection with the visit, but no part of that cost would fall upon the funds of the Institution. He thought the meeting of the two Institutions would prove beneficial to the members of both.

The following paper on "The Reaction and Efficiency of the Screw Propeller," by Mr. A. Blechynden, was then read :—

THE REACTION AND EFFICIENCY OF THE SCREW PROPELLER.

By A. BLECHYNDEN.

THE subject of the present paper is an old one in marine engineering, and it might be suggested that there are others more appropriate for to-day, but after all the years the screw propeller has been used, it can hardly be said that all is known about it, and that it has been beaten threadbare from a literary point of view.

In this paper it is the writer's intention to examine the subjects of the screw's reaction and efficiency almost wholly from an experimental point of view—to endeavour to bring forward in the light of practical experiment such facts bearing on the subject as, in his opinion, are insufficiently appreciated; but, while doing so, it is assumed that, being addressed to the members of the North-East Coast Institution of Engineers and Shipbuilders, it is addressed to those who are acquainted with the general facts of the subject, and, consequently, the paper may appear, and is, in some respects, elliptical. It is neither intended as a treatise on screw propulsion nor as an explanation of the method of designing a screw; but much that it contains is new—such, for example, as the facts bearing on the influence of surface ratio on the modulus of a screw's delivery—and the writer hopes that it may be useful in leading to a clearer appreciation of some of the phenomena connected with a screw working in water.

In order to prevent confusion and to save unnecessary words hereafter, the following definitions of terms which will be used in the paper are now given:—

"Screw" will be understood as meaning screw propeller;

"Pitch ratio" as the relation of the pitch to the extreme diameter;

"Surface ratio" as the ratio of the helical or developed surface of a screw to the area of the circle described by the tips of the blades; and,

"Projected surface" as the geometrical projection of the surface on the plane of the screw's rotation;

Screws will be termed "similar," when of equal pitch and surface ratios and with surfaces similarly distributed;

Surfaces will be described as "similarly distributed" when in screws of equal diameter the total widths of the surfaces measured at the circumferences of equal circles are equal in the two screws; and in screws of unequal diameter when the total widths of the surfaces in the two screws, measured on circles having in each the same ratio to the extreme diameters, bear to each other the same ratio as the diameters of the two screws.

In commencing to examine the subject, it would be well to glance briefly at what has up to date been regarded as the most orthodox writ upon the subject from a theoretical point of view. It cannot be invidious to single out the views of the giants in scientific investigation, Professor Rankine and Dr. Froude, more especially as those who have written upon the screw since the appearance of their memoirs upon the subject have generally adopted the views of either the one or the other.

In Professor Rankine's method of treatment which will be found at length in his paper "On the Mechanical Principles of the Action of Propellers," read in 1865 before the Institution of Naval Architects, the reaction of a propeller, whether paddle or screw, is regarded as similar to that of a jet in moving water or impinging against a moving disc and the formula for the impulse of such a jet—

$$P = A\,V\,S\,\frac{\gamma}{g}$$

is taken as the basis for the calculation of the thrust. As applied to a paddle wheel, A is the sectional area of the stream projected astern by the float, V the velocity of that stream relatively to the ship, S the velocity of the slip, γ the density of water and g the acceleration of gravity. The screw was treated as an oblique paddle and, ultimately, for practical purposes, on the assumption that the surface was sufficient to make the column or stream complete, and that the maximum impulse possible for such a stream is that of a jet of equal speed and slip and a sectional area equal to the screw's disc, the same formula multiplied by a co-efficient of delivery depending on the pitch ratio of the screw was used to calculate the thrust. Probably there has not yet been a more thoroughly practical formula framed whereby to calculate the thrust of a screw, and had it only been accompanied by some definite means of determining the relation of the co-efficient of delivery to the quantity of

surface little more would have been left to be desired. There is also a most interesting article on the screw of maximum efficiency published amongst Rankine's miscellaneous papers, which, from his point of view, is that which has such a curvature of blade from fore to aft as shall uniformly accelerate the water as it traverses the screw.

Mr. Froude, in his paper "On the Elementary Relation between Pitch, Slip, and Propulsive Efficiency," read before the Institution of Naval Architects in 1878, starts from a different point of view. Each element of the blade is viewed as a plate moving in a rectilineal path oblique to its surface, and the normal pressure upon it per square foot of area is taken as :—

$$P = 1{\cdot}7 \text{ Sin. } \theta \, V^2,$$

V being the velocity in feet per second and θ the angle between the plane and its line of motion, or, the slip angle. Expressions are then found for the resistances of the plane resolved parallel and normal to the axis of rotation, a deduction being made from the thrust and an addition to the turning force for the effect of fluid friction, and from these an expression is found for the efficiency. Then there follows an interesting investigation of the blade angle of maximum efficiency, from which Mr. Froude concludes that it is 45 degs. with the plane of rotation with a slip of 12½ per cent., the efficiency being then 77 per cent.

It must be remembered that the said investigation relates to an elementary blade only, so that, assuming the whole data upon which the investigation rests as sound and the investigation accurate, still it serves only to point out how the whole blade must be treated. The pitch ratio of maximum efficiency is still left undetermined. As a general method of calculating the thrust of a screw it cannot be recommended, as it involves the assumption that the thrust is directly proportional to the blade surface of the screw, which shall be shown hereafter to be very wide of the mark, and, it might be added, very little reasoning is needed to prove it necessarily so.

The method of treatment pursued by Mr Froude commends itself to the judgment as the more rational of the two alluded to, because the reaction of the screw is that due to its blades moving in paths inclined to their faces, the inclination being the slip angle, and the thrust is this reaction resolved in a direction parallel to the axis of rotation; but this thrust is limited by the value of the impulse of a stream or jet of equal speed and slip and of section equal to the disc area of the screw. This is the maximum value of the thrust whatever be the blade area or pitch, so that it would appear as if some combination should be made of

the two methods—such, in short, as Professor Cotterill has attempted in his paper "On the minimum area of Blade in a Screw Propeller necessary to form a complete column." This can be referred to in the "Transactions of the Institution of Naval Architects" for 1879.

Experimental data in such a simple form as will enable general deductions respecting a screw's reaction to be made are comparatively scarce, although it is probable that there is no machine made by engineers with which more experiments have been made in the concrete form; but the data of such experiments are of little value unless there exists the means of separating the frictional and other resistances from the gross power applied to the screw, and the thrust and ship's resistance be known.

Some of the most valuable data—valuable chiefly because of the skill and care of the observer—were published in Vols. XX. and XXI. of *Engineering*, under the title of "Propelling Efficiency of Screws," by Mr. B. F. Isherwood.* The paper gives the carefully analysed results of a series of trials of different screws on a steam launch. As these trials will be frequently referred to and their data made use of to prove certain propositions, a brief outline of them may not be out of place.

The object in view was to ascertain the relative efficiency of different screws at different speeds.

In order that the power expended in working the screw and propelling the vessel might be separated from the total power developed, the friction of the engine and shafting was carefully ascertained by independent trials. The thrusts were measured by a dynamometer. The vessel was carefully tried over a measured distance at various speeds, varying from 5 to over 8 knots, with each screw, and the results plotted down.

From the total powers thus found for the various speeds were deducted the powers expended in the friction of the engine and shafting and the remainder was divided into three parts, viz.:—

1st—The power absorbed in the friction of the screw (calculated);
2nd—The power expended in slip; and
3rd—The power expended in overcoming the resistance of the ship.

The powers under the second and third heads were found by deducting the power expended in the screw's friction from the total power trans-

* As it would be inconvenient to reproduce the tabular analyses of these trials on account of their length, the reader is referred to pages 369 and 370, Vol. XX., *Engineering*, November 5th, 1875.

mitted to the screw and then by dividing the remainder into two parts proportionate respectively to the apparent slip and to the speed of the vessel. The last is the power expended in propulsion, and its relation to the total power, less that expended in engine friction *per se*, was taken as the propulsive efficiency of the screw.

The following Table gives the particulars of the screws tried :—

TABLE I.

Designation of Screw.	Diameter in Feet.	Diameter of Boss in Feet.	Pitch in Feet.	Number of Blades.	Length on Axis in Feet.	Area of Blades in Feet.	
						Projected.	Helicoidal.
A	4·333	0·50	5·136	2	0·9167	5·1950	6·1321
B	4·333	0·50	5·136	2	0·7187	4·0730	4·8078
C	4·333	0·50	5·136	2	0·4583	2·5975	3·0661
D	4·333	0·50	5·136	2	0·2604	1·4755	1·7417
E	4·333	0·50	5·136	4	0·4583	5·1950	6·1321
F	4·333	0·50	5·136	4	0·4583	5·1950	6·1321
G	4·333	0·50	7·00	3	0·9167	5·0140	6·8520
H	4·333	1·25	7·00	3	0·9167	2·7495	5·2968

The screws A, E and F were formed from two two-bladed screws which were slices of a double threaded helix, of which the screw C was one tried separately. They were made so that they could be fixed at right angles and so form a four-bladed screw E, directly behind each other as a Mangin screw F, or, angularly with the after edge of the forward screw touching the forward edge of the after one and so form one two-bladed screw A ; the screw G was of the same class as A ; and the screw H of the Griffith form made by paring down the blades of the screw G and fitting filling pieces around the boss.

It may be interesting to give the dimensions of the launch upon which these screws were tried though it is not absolutely necessary for the purposes of this paper.

DIMENSIONS OF U.S. STEAM LAUNCH No. 4.

Length on water line		54·40 feet.
Extreme breadth on water line		11·88 „
Draught—Forward... ...	2·957 feet	Mean 3·885 „
„ Aft	4·813 „	
Greatest transverse section		24·98 square feet.
Displacement		814·10 cubic feet.
Co-efficient of lines		0·600

In the years 1882 and 1883 a very large number of experiments were made with model screws at Messrs. R. & W. Hawthorn's Forth

Banks Works. These experiments were undertaken with the object of ascertaining the effect which modifications of the form of blade have upon the performances of screws, but they were afterwards extended to modifications of pitch ratios, and in all twenty-five models of various forms and proportions were experimented with. These were tried in the tank and with the apparatus shown in Figs. 1 and 2, Plate 27. During the trials the free water level was 4 inches over the tips of the blades of the screws of 14½ inches diameter and this total depth of water was kept the same for all. The screw, in rotating, caused the water to course around the tank in the direction of the arrow, so that the thrust was due to the frictional resistance of the water against the sides and its deflection at the ends of the tank. Thus, the slips were not under control, and, as it happened, were much greater than in the ordinary conditions under which screws work; but, notwithstanding this defect, the experiments possess great value and serve to prove some important propositions respecting the reaction of the screw.

The most important of the experiments were made with a set of screws of the same diameter, surface ratio and form of blade, but of different pitch ratios; and with a set of three similar screws of different dimensions. The following Table gives the dimensions of those models to whose trials reference will be made hereafter:—

TABLE II.

Designation of Screw.	Diameter in Inches.	Pitch Ratio.	Pitch in Inches.	Number of Blades.	Surface in Square Inches.	Surface Ratio.	Form of Blade and Remarks.
a	14·5	1·25	18·125	4	63	0·38	Parallelogram, Fig. 3, Plate 28.
b	14·5	1·25	18 125	2	31·5	0·19	Do.
c	14·5	1·075	15·65	4	63	0·38	Blade shown in Fig. 4, Plate 28.
d	14·5	1·103	16·00	4	63	0·38	Do.
e	14·5	1·172	17 00	4	63	0·38	Do.
f	14·5	1·25	18·125	4	63	0·38	Do.
g	14·5	1·353	19·625	4	63	0·38	Do.
h	14·5	1·449	21·00	4	63	0·38	Do.
j	14·5	1·60	23·20	4	63	0·38	Do.
k	14 5	2·00	29·00	4	63	0·38	Do.
l	9·625	1·254	12·0625	4	27·7	0·38	Blade proportioned same as Fig. 4
m	21·75	1·25	27·1875	4	142	0·38	Do.
n	21·75	0·833	18·125	4	142	0·38	Do.
o	14·5	1·25	18·125	4	92	0·556	Parallelogram, Fig. 3.
p	14·5	1·25	18·125	4	63	0·38	Fantail, Fig. 5, Plate 28.
q	14·5	1·25	18·125	4	63	0·38	Griffith's, Fig. 6, Plate 28.

NOTE.—Since the greater portion of this paper was written, experiments have been made by the writer with the same apparatus and with screws similar to the above with three and two blades. The results are embodied in the paper.

These models were tried in nearly all cases at twenty-three different speeds, at two different times, and the mean revolutions taken by counter over a period of four minutes. The results for each screw shaped themselves into the three general equations—

$$T = C_1 W \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$
$$T = C_2 R^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$
$$R = C_3 \sqrt{W} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

in which T is the thrust, R the revolutions, W the motive weight and C_1, C_2 and C_3 three co-efficients constant for each screw, any one of which is deducible from the other two, but each of which was calculated from the results independently and then compared. In analysing the results of these experiments, the whole have been reduced as for a common thrust of 5·6 lbs., which includes, with the indicated thrust, a calculated allowance for the effect of fluid friction upon the blades.

The source from which any other fact is derived will be given in the course of the paper.

An attempt will now be made to prove certain propositions respecting the screw's reaction. The effects of friction and edge resistance in modifying the efficiency of the screw will then be considered and, finally, the influence of the screw's dimensions and proportions on propulsive economy will be briefly viewed.

The following propositions must be understood as referring to screws without frictional or edge resistances, though this may not be distinctly stated in each, and as true only within the limits proved by experiment. All may be true for much wider limits—induction would point to that supposition—but, as the experimental proofs of most of them extend over the range embraced by practice, the residual phenomena may be left for the present.

PROPOSITION I.—*In any screw the turning moment is independent of the quantity of surface or of the mode in which it is distributed.*

This is a conclusion arrived at by Mr. Isherwood and is clearly proved by his experiments.

Of the various items into which the mean pressures and powers are divided in Mr. Isherwood's analyses of his trials with the several screws in steam launch No. 4, only those due to slip and propulsion affect the

present proposition. These are the pressures and powers due to the screw's reaction. All the screws from A to D are equal in diameter and pitch but widely different in surface ratio. Screws G and H are also equal in diameter and pitch but have surfaces different in quantity and mode of distribution. If, therefore, it can be shown that the turning moments of the set of screws A to D are equal to each other for equal speeds and that those of G and H are equal for equal speeds, the proposition may be held as proved. It is not necessary that the absolute turning moments be taken, as the lever—in this case the crank of the engine—being constant throughout, they are proportionate to the piston pressures which may be compared instead of them.

In Tables III. and IV. the sums of the pressures for slip and propulsion are shown for each speed and each screw; and it will be seen that with screws of the same diameter and pitch ratio the pressures are equal for equal speeds. Such slight differences as exist are well within the limits of errors of observation. Yet, while this equality exists for screws of the same diameter and pitch ratio when tried at equal speeds, the surfaces vary enormously: in the A F set from 6·1321 down to 1·7417 square feet.

TABLE III.

GIVING PISTON PRESSURES DUE TO REACTION OF SCREWS FOR VARIOUS SPEEDS.

Screws 4·33 feet diameter and 5·16 feet pitch, but with different surface ratios.

Screw.	Surface in Feet.		Speed in Knots per Hour.							
	Helical.	Projected.	8·5.	8·0.	7·5.	7·0.	6·5.	6·0.	5·5.	5·0.
A, E, F	6·1321	5·1950	59·0757	54·0728	47·3228	38·5841	30·6216	24·5562	20·1285	17·2154
B	4·8078	4·0730	59·0744	54·0706	47·3110	38·5884	30·5992	24·5580	20·1286	17·2157
C	3·0661	2·5975	59·0352	54·0074	47·3277	38·5947	30·3824	24·5896	20·0912	17·1464
D	1·7417	1·4755	59·2600	54·0847	47·3342	38·5829	30·6698	24·5549	20·1335	17·2139

TABLE IV.

GIVING PISTON PRESSURES DUE TO REACTION OF SCREWS FOR VARIOUS SPEEDS.

Screws 4·33 feet diameter and pitches 6·5 feet at forward edge, increasing to 7·5 at after edge.

Screw.	Surface in Feet.		Speed in Knots per Hour.							
	Helical.	Projected.	8·5.	8·0.	7·5.	7·0.	6·5.	6·0.	5·5.	5·0.
G	6·8520	5·0140	80·5234	73·6961	64·5006	52·5878	41·7009	33·4674	27·4355	23·4632
H	5·2768	2·7495	80·5107	73·6979	64·5037	52·5904	41·7029	33·4678	27·4350	23·4630

PROPOSITION II.—*Screws of equal diameter tried under similar conditions have turning moments directly proportional to their pitch ratios for equal thrusts.*

If the turning moments, or rather their equivalent piston pressures in Table III. be compared with those in Table IV., it will be found that for the same speed they bear the ratio of 1 to 1·36 throughout. If now the pitch of the first set of screws be compared with the arithmetical mean of the pitches of the second set their ratio will be found to be 1 to 1·356, which is practically equal to the ratio of the piston pressures.

In the following Tables (No. V. and No. VI.) and in Fig. 10, Plate 31, the relation between the pitch ratios and the turning moments is more forcibly and satisfactorily illustrated because of the wide range of pitch ratios which it embraces and also because of the fact that the pitches of all the screws are uniform, while in the case of the screws just referred to, the comparison was made between the results from a set of screws of uniform and those from a set of screws of non-uniform pitch, a fact which might reasonably throw doubt upon any general deduction respecting the influence of pitch ratio on turning moment which might be made from their trials.

TABLE V.

SHOWING THE MOTIVE WEIGHTS OF EXPERIMENTAL SCREWS COMPARED WITH THEIR PITCH RATIOS.

Diameter of all screws 14·5 inches. The motive weights are in lbs. acting at 6·125 inches radius for a thrust of 5·6 lbs.

Screw.	Pitch Ratio.	Motive Weight. lbs.	Ratios.	
			Pitches.	Motive Weights.
c	1·075	2·270	1·000	1·000
d	1·103	2·316	1·026	1·020
e	1·172	2·479	1·090	1·092
f	1·250	2·589	1·156	1·140
g	1·353	2·872	1·259	1·265
h	1·449	3·010	1·348	1·326
j	1·600	3·428	1·488	1·510
k	2·000	4·245	1·860	1·870

TABLE VI.

SHOWING THE MOTIVE WEIGHTS OF EXPERIMENTAL SCREWS COMPARED WITH THEIR PITCH RATIOS.

Diameter of the screws 21·75 inches. The motive weights are in lbs. acting at 6·125 inches radius for a thrust of 5·6 lbs.

Screws.	Pitch Ratio.	Motive Weight. lbs.	Pitches.	Motive Weights.
a	0·833	2·560	1·000	1·000
m	1·250	3·810	1·500	1·455

It appears that this law holds for all pitch ratios from 0·833 to 2·00, or throughout the limits of ordinary practice. Examples of screws having pitch ratios higher and lower than those just given may be found, but very rarely.

PROPOSITION III.—*Screws with equal pitch ratios have turning moments proportional to their diameters when indicating equal thrusts.*

TABLE VII.

GIVING THE RESULTS OF THE TRIALS OF THREE SIMILAR SCREWS OF DIFFERENT DIMENSIONS.

The motive weights are given for a lever of 6·125 inches and a thrust of 5·6 lbs.

Screw.	Diameter in Inches.	Pitch in Inches.	Pitch Ratio.	Motive Weight. lbs.	Pitches.	Diameters	Motive Weights.
l	9·625	12·0625	1·253	1·695	0·6655	0·666	0·656
f	14·500	18·1250	1·250	2·589	1·0000	1·000	1·000
m	21·750	27·1875	1·250	3·810	1·5000	1·500	1·470

The figures in Table VII., embracing examples having diameters in the ratio of 1·00 to 2·25, seem sufficient to prove the proposition.

PROPOSITION IV.—*Screws tried under similar circumstances have turning moments proportional to their pitches when indicating equal thrusts.*

This follows from Propositions II. and III., because if the turning moments be proportional to $\frac{P}{D}$ in screws of equal diameters and to D in screws of equal pitch ratios, then $M \propto \frac{P}{D} \times D$, $\therefore M \propto P$, where M is the turning moment, P the pitch and D the diameter of the screw.

PROPOSITION V.—*In any screw* $T \times P = 2 \times \pi \times M$ (*i.e., thrust into pitch is equal to* 6·28 *into the turning moment*).

This proposition may be put in other words. The thrust in lbs. multiplied by pitch in feet and revolutions per minute and divided by 33,000, is equal to the net horse-power exerted in turning the screw. This appears so self-evident as to need no proof. It is nevertheless well to prove it. It follows from Proposition II. that for the same thrust pressures the indicated thrusts must be directly proportional to the indicated powers, since the pitches and the motive weights are proportional and the thrusts and lever orbits are constant; but it does not follow from this that they are equal. Observations of results, however, indicate equality and the following Tables clearly illustrate it.

TABLE VIII.

SHOWING THE RELATION BETWEEN PITCH × THRUST AND MOTIVE WEIGHT × LEVER ORBIT IN EXPERIMENTAL SCREWS FOR A THRUST OF 5·6 LBS.

Screw.	Pitch in inches.	Motive weight in lbs.	Pitch × Thrust.	Orbit × Motive weight.
c	15·650	2·270	87·64	87·35
d	16·000	2·316	89·60	89·12
e	17·000	2·479	95·20	95·39
f	18·125	2·589	101·50	99·62
g	19·625	2·872	109·90	110·51
h	21·000	3·010	117·60	115·81
j	23·1875	3·428	129·85	131·90
k	29·000	4·245	162·40	163·35

TABLE IX.

SHOWING THE RELATION BETWEEN INDICATED THRUST AND POWER EXPENDED IN "PROPULSION" AND "SLIP" IN THE CASE OF MR. ISHERWOOD'S TRIALS WITH SCREWS A, E AND F.

Speed in knots	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5
Thrust by dynamometer lbs.	315.4	368·8	449·9	560·6	707·0	867·1	990·7	1082·4
Revolutions per minute	107·125	118·544	130·030	141·690	153·778	167·482	182·296	196·501
Slip per centum	7·82	8·37	8·87	9·40	10·10	11·56	13·33	14·57
"I.H.P. for propulsion" ..	4·847	6·235	8·297	11·200	15·211	19·989	24·361	28·280
"I.H.P. for slip"	0·411	0·569	0·808	1·171	1·709	2·613	3·747	4·823
I.H.P. for propulsion and slip ..	5·258	6·804	9·105	12·371	16·920	22·602	28·108	33·103
Thrust horse-power	5·257	6·805	9·115	12·350	16·910	22·580	28·100	33·100

It will be observed that approximate equality exists between columns 4 and 5 of Table VIII. and lines 7 and 8 of Table IX.

The same fact might be illustrated by other examples, but those given showing the truth of the proposition for screws of different pitch ratios when indicating the same thrust and for the same screws at different speeds are sufficient.

PROPOSITION VI.—*The thrust* T *of any screw working with a velocity of advance* V *and a slip* S *can be approximately determined from the equation—*

$$T = \frac{C A V S \gamma}{g}$$

A *being the disc area of the screw,* γ *the density of water,* g *the acceleration due to gravity and* C *a modulus depending on the pitch and surface ratios of the screw.*

This will be recognised as the expression given by Rankine for the thrust of a propelling instrument and it is equivalent to saying that for a given speed of screw the thrust varies as the slip.

The forward thrust of a screw can only be due to the backward velocity impressed upon the water passing through it, and it would appear but a rational deduction that if, with the same speed of advance, the slip were doubled, or, in other words, double the backward velocity impressed, the thrust would be doubled. Let Table X. be considered. It gives the co-efficient C worked out for three similar screws of different dimensions indicating the same thrust. The speed of stream is the same for each; but their speeds of advance and slips are different, as they must necessarily be, for the same thrust to be indicated.*

TABLE X.

SHOWING THE RESULTS OF TRIALS AND THE MODULUS C FOR THREE SIMILAR SCREWS *l*, *f* AND *m* WHEN INDICATING 5·6 LBS. THRUST.

Screw.	Pitch in Feet.	Diameter in Feet.	Revolutions.	Speed of Advance in Knots.	Current in Knots.	Slip in Knots.	Net Area in Sq. Ft.	C.
l	1·005	0·802	250·5	2·484	0·630	1·854	0·461	0·479
f	1·510	1·208	115·0	1·714	0·630	1·084	1·105	0·496
m	2·265	1·812	57·9	1·294	0·630	0·664	2·535	0·467

* The expression for thrust becomes T = 5·5 C A V S when A is in square feet, T in pounds, V and S in knots per hour and the screw is acting in fresh water.

The values of C thus calculated are approximately equal, but they work out still more nearly so if a very simple and admissible convention be adopted. It has been shown that the turning moments of screws are as their pitches. There is then no reason why the turning moments should not be regarded as the criterion of pitch. It is extremely difficult to make model screws with pitches as accurately as intended, especially if the blades are filed and burnished after they are fixed. Therefore the true pitches might for convenience be calculated from the turning moments. Let this convention be adopted.

If the figures in the sixth column of Table VII. be compared with those in its eighth column it will be observed that the ratios of the pitches of the screws *l* and *m* are greater than the ratios of their motive weights, so that if it be assumed that the pitch of the screw *f* is correct as stated on that table, then the pitches of *l* and *m* must be less than they were intended to have been. In order that they should have the same relation to their motive weights as the pitch of the screw *f* has to its motive weight, the pitch of *l* must be 0·988 feet and that of *m* 2·220 feet, and the results shown in Table XI. would follow if the same calculations be made with these assumed pitches as were performed for Table X.

TABLE XI.

SHOWING THE VALUES OF C FOR THE SCREWS *l*, *f* AND *m*, THE PITCHES BEING ASSUMED PROPORTIONAL TO THE MOTIVE WEIGHTS, FOR A THRUST OF 5·6 LBS.

Screw.	Pitch in Feet.	Pitch Ratio.	Coefficient C.
l	0·988	1·232	0·499
f	1·510	1·250	0·496
m	2·220	1·225	0·496

The screws now appear with approximately equal moduli.

The equation $T = \frac{C A V \gamma}{g} S$ may be regarded as the equation to a straight line referred to the co-ordinates T and S if the part $\frac{C A V \gamma}{g}$ be constant, so that, for a given screw and speed of advance, a diagram such as that shown in Fig. 7, Plate 28, may be used to determine the thrust for any slip ratio, the thrust for one slip ratio being known. It is only required to measure off on the base AB the slip AS to any scale, and from the point S to draw S*t* perpendicular to AB, proportionate to

the thrust, to the same or any other scale, and through l and A to draw the straight line AC. The co-ordinates of any point in AC will be slip and its corresponding thrust to the same scales as before.

In harmony with this proposition, thrust increases with the disc area and with the speed of advance. The thrust for a screw similar to l working with the same slip *ratio*, but equal in diameter to m, can therefore be calculated by multiplying the thrust, 5·6 lbs., by the ratio of the area, and then by the ratio of the squares of the advances of l and m. The result is $5{\cdot}6\frac{2{\cdot}535}{0{\cdot}461}\left(\frac{1{\cdot}268}{2{\cdot}442}\right)^2 = 8{\cdot}302$ lbs. Thus, three points in the thrust curve for a screw of 1·228 pitch ratio (the mean of the ratio of l and m) are known, viz. :—0, 5·6 and 8·3, their respective slip ratios being 0, 0·503 and 0·742. These points, when plotted down in the manner mentioned in the last paragraph, range almost in a straight line. This is shown in Fig. 7, Plate 28.

As a further illustration of Proposition VI., the diagram, Fig. 8, Plate 29, is given, which is an analysis of trials made with a screw 9 inches diameter at various speeds. This is the model whose trials are published in Mr. Sidney Barnaby's book, "Marine Propellers," but with the thrusts calculated for the uniform speed of advance equivalent to 930 revolutions per minute. The thrusts, plus a calculated amount for friction, are plotted down in reference to their slip ratios. These slip ratios are not calculated upon the mean but upon the after pitch of the screw, as it is evident that upon the after pitch the true advance of the screw depends. Agreeably with the proposition it will be seen how closely five out of the eight trial spots range in a straight line and that the greatest divergence of the others is within the limits of ordinary errors of observation.

Corollary :—With constant slip ratio the thrust varies as the square of the revolutions or the square of the advance.

PROPOSITION VII.—*The effect of surface is the same irrespective of the number of blades into which it is divided so long as it is similarly distributed.*

This is evident from Mr. Isherwood's trials with the screws A, E and F. Each had the same quantity of surface and that surface similarly distributed. A had two blades; E had four blades, each adjacent pair being at right angles; F was a screw of the Mangin form; each screw gave the same result.

The influence of the pitch and surface ratios on the value of the modulus C *of Proposition VI.*

The mode in which the modulus C varies with the surface ratio will be best apprehended by reference to the diagram, Fig. 9, Plate 30, which is a curve drawn in the first instance through the values of C for the screws *o*, *a* and *b* as ordinates with their respective surface ratios as abscissæ. These are screws with similarly distributed but different quantities of surface. The four points f_4, f_3, f_2 and f_1 were plotted on the assumption that—A curve of C values for any pitch ratio referred to the surface ratios as abscissæ being given (the mode of distribution being the same for all the surface ratios) the same curve may be used to determine the C values for screws with surfaces distributed in any other mode, the C value for one screw of the kind being known. All that is necessary is to find the abscissa for the known C value. Similar screws with other surface ratios will have C values equal to the ordinates of their proportionate abscissæ.

The point f_4 has an ordinate equal to the C value of the screw *f*. The ordinates of the points f_3, f_2 and f_1 are the values found by experiment for screws with three, two and one similar blades to *f* referred to the abscissæ 0·75, 0·50 and 0·25 of the abscissa of f_4. It will be seen how closely they coincide with the curve.

The curve is drawn for a set of screws of 1·25 pitch ratio and its ordinate appears to approach a limit of 0·64. It is noteworthy that this is about the maximum physical limit for a screw of this pitch ratio working with 25 per cent. slip according to the investigation of Professor Rankine.

An examination of the curves of C values for other pitch ratios indicates that, for practical purposes, the curve may be regarded as the same for all pitch ratios between 1·0 and 2·0, but with its co-ordinates to different scales. For the pitch ratio of 2, for example, the C values for the screw *k* and for screws with three and two similar blades are shown by the points k_4, k_3 and k_2, the latter pair having abscissæ proportioned in the ratios of 0·75 and 0·50 to that of k_4, and the ordinates to such a scale that the maximum height of the curve equals 0·46. The points almost coincide with the curve.

The particular value of C for any distribution of surface appears very difficult to determine except by experiment, but a very close approximation may be made by comparison with the known values for certain distinct types of blades. Table No. XII. illustrates the variation of C with variation in the mode of distribution of surface. The four screws

whose values it embraces have equal pitch and surface ratios, but their surfaces differently distributed. The forms of the blades are shown in Figs. 3, 4, 5 and 6, Plate 28.

TABLE XII.

Screw.	Diameter. Inches.	Pitch. Inches.	Pitch Ratio.	C.	Ratio of C.
q	14·5	18·125	1·25	0·482	0·869
f	14·5	18·125	1·25	0·496	0·892
a	14·5	18·125	1·25	0·556	1·000
p	14·5	18·125	1·25	0·580	1·044

It is evident from the table and the diagrams, as might be expected, that the greater the moment of the surface relatively to the axis the greater is C.

An examination of the results of experiments with the *c k* series* of screws shows that the revolutions for any pitch ratio within the limits of trial can be expressed by the empirical formula $\left(\frac{k_1}{p} + k_2 p\right) \sqrt{\mathrm{T}}$, k_1 and k_2 being constants, p the pitch ratio and T the thrust in lbs. Its close agreement with the trial results will be seen by an inspection of the figures in Table XIII., and of Fig. 10, Plate 31, which is a general analysis of the trials of these screws for 5·6 lbs. thrust. For this thrust the revolutions equal $\frac{111}{p} + 22p$.

TABLE XIII.

SHOWING THE CALCULATED AND EXPERIMENTAL REVOLUTIONS FOR THE *c k* SERIES OF SCREWS FOR 5·6 LBS. THRUST.

Screw.	Pitch Ratio.	Revolutions per Minute by	
		Experiment.	Formula.
x	0·833	149·0	151·3
c	1·075	127·6	126·6
d	1·103	125·0	124·9
e	1·172	121·0	120·5
f	1·250	115·0	116·5
g	1·353	111·6	111·9
h	1·449	106·6	108·5
j	1·600	104·4	104·6
k	2·000	99·8	99·5

* By the *c k* series of screws is meant all those screws from *c* to *k* inclusive in Table II.

The screw x is hypothetical being proportioned from the C value of n.

If the formula $\left(\frac{k_1}{p} + k_2 p\right) \sqrt{\text{T}}$ be multiplied by the pitch it gives the advance in feet per minute. For 5·6 lbs. thrust this is $111\text{D} + \frac{22\text{P}^2}{\text{D}}$ (D being diameter and P pitch in feet). One term, 111D, is constant, the other, $\frac{22\text{P}^2}{\text{D}}$, varies with the square of the pitch.

If it be assumed that this formula is true for all pitch ratios, and from it the curve of advance, CC of Fig. 10, be traced out, the curve will cut the axis of ordinates, when the pitch ratio has become zero, at a height 111D. In the diagram this height is the equivalent of 111D in knots per hour = 1·324. The question naturally arises—Has this any physical meaning?

It has been stated already that a screw of given disc area, speed of advance and slip, has a maximum limit of thrust. It follows also from this that any screw with given speed of feed and thrust has a minimum speed of advance. This speed of advance V (= v_1 + S, v_1 being the speed of feed) can be found from the equation C $\frac{\text{AVS}\gamma}{g} = \text{T}$ of Proposition VI., with a C value = unity.

It is remarkable that 1·324 knots, with 0·63 knots speed of feed, which was the speed of the current in the tank, gives just 5·6 lbs. thrust for a stream of the same disc area as these screws, thus—

Disc area — area of boss = 1·105 square feet.

Thrust = 1·105 × 1·324 × (1·324 − 0·63) × 5·5 = 5·6.

It ought to be stated that the empirical formula was found in the first instance to cover the revolutions in the experiments and that this point was led up to by precisely the mode of reasoning given. This position was by no means reasoned from.

The minimum limit of advance just referred to is for a pitch ratio indefinitely reduced, but each pitch ratio has a minimum limit of its own greater than this. This will be seen by the fall in C values with increase of pitch in Fig. 10, Plate 31, and their approach to limiting values as shown in Fig. 9, Plate 30. This minimum advance appears to coincide approximately with that which would be given by Rankine's calculation.

A very little consideration will show that it is impossible to lay down any particular set of ratios giving the values of C for screws with different surface ratios or with different numbers of blades of the same pattern.

The relation which subsists between its values for screws of one pitch ratio with different numbers of the same blades depends upon the particular value of C for any one of the screws. The position of that point on the curve being fixed the value for the others may be determined, but these values hold for that pitch ratio only. For other pitch ratios they fall upon different parts of the curve and have different values. The following are examples:—

TABLE XIV.

TABLE OF THE RELATIVE C VALUES OF SCREWS WITH DIFFERENT NUMBERS OF BLADES OF THE SAME AND OF DIFFERENT PITCH RATIOS AS DETERMINED BY EXPERIMENT.

Pattern of Blades.	Number of Blades.			Pitch Ratio.
	Four.	Three.	Two.	
Same as *a*	1·00	0·862	0·628	1·25
Do. *f*	1·00	0.810	0·617	1·25
Do. *f*	1·00	0·765	0·556	2·00

The modulus C becomes unity for all surface ratios when the pitch ratio is indefinitely decreased, so that, if a series of curves for the values of C for different surface ratios be drawn relatively to the pitch ratio as abscissæ, as in Fig. 10, they will osculate at zero pitch ratio, diverge with increase of pitch ratio up to a certain point, and it may be reasonably concluded that they would re-approach each other and finally re-osculate as the pitch ratio is increased indefinitely. Curves of their actual values for certain surface ratios and patterns of blades are shown by the curves D D_4, D D_3 and D D_2 in the diagram referred to. All are hypothetically continued to the axis of ordinates on the same principle as that for the *c k* series with four blades, viz.:—the curve D D_4.

For practical purposes of comparison for small variations of similarly distributed surface in screws of the same pitch ratio, C may be regarded as varying with the square root of the surface ratio, but this is a rough approximation only.

Varying Pitches.—The preceding relates to screws of uniform pitch, but the same may be held as true for those with non-uniform but equivalent mean pitches. Such screws may be divided into two main classes in regard to the pitch's mode of variation, namely—

(a) The pitch varying (generally increasing) from boss to circumference.

(b) The pitch increasing from leading to following edge of blade.

In some screws the two modes (a) and (b) are combined and sometimes —most probably the result of accident rather than design—the pitch at the boss exceeds that at the periphery.

The turning moments of model experiments indicate that in class (a) the equivalent mean pitch is $\frac{\Sigma r p}{\Sigma r}$ in which $\Sigma\, r p$ means the sum of the radii at equal intervals each multiplied by the pitch at that radius, and $\Sigma\, r$ the sum of the radii. The revolutions of such a screw are equal to the revolutions of one of equal diameter having an equal quantity of similarly distributed surface and an equivalent uniform pitch, both being tried under the same conditions.

Mr. Isherwood's experiments indicate that in screws with pitches of class (b) the mean pitch referred to the turning moment is the arithmetical mean of the two. Referring to Tables III. and IV., as was shown under Proposition II., the relation between the mean pressures for any speed in Table III., and for the same speed in Table IV., was as 1·0 to 1·36. The set of screws under Table III. had a uniform pitch of 5·16 feet and those under Table IV. had pitches varying from 6·5 to 7·5 feet. Now $5{\cdot}16 : 7 = 1 : 1{\cdot}356$ — practically the same as the ratio of the piston pressures.

An examination of the results of Mr. Isherwood's two screws A and G shows the performance of G to be very high. Though its mean pitch is 7 feet against 5·16 in A, its slip is practically the same, viz., 14·5 per cent.* As has been already stated, however, slip is due to the ultimate, not to the mean pitch so that its slip ought to be calculated on 7·5 feet pitch instead of 7 feet pitch.

It would thus appear that the supposition that an axially increasing pitch is an advantage is borne out by this experiment, since the turning moment is that proportional to the mean, and the slip is that due to the ultimate pitch.

NOTE.—It may be well to call attention to the fact that in a screw whose pitch varies in the mode (a), the working face of which is swept out by a lath moved over templates at the boss and periphery, the pitch does not increase uniformly from the boss to the periphery; but that if a pitch curve be drawn such as $O\ p\ P$ in Fig. 11, Plate 28, it shows the pitch to increase very rapidly with increase of radius towards the root and much less rapidly towards the periphery. What is meant by a pitch curve is a curve such that the distance $r\ p$ measured from the vertical axis O Y parallel to the axis of the screw O X at any radius O r is proportional to the pitch at that radius.

* See foot note, page 182.

Curvature of Developing Surface, etc.—Experiments were tried at Forth Banks to ascertain the effect of curvature of blade and of its position on the boss. The set of models experimented upon were of the same diameter, pitch ratio and surface ratio, and each with its surface similarly distributed relatively to its moment round the axis. The results of these experiments showed that in undisturbed water and with free feed blades inclined forward or backward in an axial direction and blades concave like a sickle towards the direction of rotation or curved backward convexly towards the direction of rotation were equal in effect to a simple symmetrical blade within the limits of the experiments. From this it appears clear that any two screws of equal diameter, pitch and surface, so long as the surfaces be similarly distributed, will, under the same circumstances, give the same result irrespective of the distribution of the surface in other directions. In the case of the two screws being applied to ships the results might be different, as it is a clearly ascertained fact that the further the screw be moved aft from the ship the more effective will it be as a propelling instrument, so that throwing the blades backward on the boss, which is equivalent to moving the screw bodily back, might reasonably be expected to give a higher propulsive effect than blades wholly central, but this is equivalent to screws working under different circumstances. The circumstances might be the same as far as propelling similar ships is concerned, but widely different as to the freedom of the feed.

Fluid Friction on Blades and Edge Resistance.—Dr. Froude's experiments, the results of which he made public in 1872, show that the co-efficient of friction decreases with increase in length of surface and that with ordinary painted or varnished surfaces it varies with the 1·83 power of the velocity.

Co-efficients deduced from these experiments will be found in the Appendix to this paper and in the diagram, Fig. 12, Plate 32.

In the calculation of the frictional resistance of screws it has been an open question whether the helical path of each element should be taken as having a pitch equal to the screw or that pitch less slip. The latter view was adopted by Dr. Froude in the text of his paper of 1878, but he stated afterwards in a note to the same paper that he had changed his opinion. By later experiment, however, he found that the inclination of the blade to the line of motion, or, in other words, the slip appeared con-

siderably to modify the frictional resistance, as might, perhaps, looking at the subject after the fact, be reasonably expected. Quoting his own words,

> Experiments . . . show conclusively that the decrease in efficiency consequent on increased slip with screws of ordinary proportion is scarcely perceptible even when the slip is as large as 30 per cent. with the screw working in undisturbed water. The results so shaped themselves as to point to the conclusion that for some reason or other the co-efficient of surface friction began to diminish when the slip ratio became as much as 15 per cent., and was about halved when the slip ratio was 30 per cent.; and as it appeared not improbable that with increasing slip a more or less pronounced eddy might become established at the back of the blade so as more or less completely to neutralise the friction on the surface, a rough experiment was tried by moving a plane obliquely through the water with various angles of slip, and in a position where the effect could be observed; and in point of fact it appeared that when the angle between the plane and its line of motion was about 10 degrees, the water at its back had assumed the form of an eddy, having nearly the speed of the plane, and that it in fact overran the plane when the angle was increased to 15 degrees.*

It appears, then, that if the convention of calculating the friction for the helix whose pitch is the pitch of the screw less the amount of slip per revolution be adopted the results will agree closely with Dr. Froude's experiment.

It is quite possible that there is another cause of the greater apparent frictional resistance at low slips which does not appear in the explanation just given, viz., the edge resistance is much greater at low than at high slips.

If a screw of uniform pitch as regards its working face be moved through the water without slip relatively to this face, the only resistance due to this side will be frictional. With the back, however, it is different. As will be seen by reference to Fig. 14, Plate 34, the side $c\,a$ encounters resistance due to the impulse impressed upon the water in its path; and a screw so moved would be working with true negative slip and would, from this cause, have negative thrust. Now, let it be supposed that such a section as is shown in Fig. 14, instead of moving in a path $a\,b$ parallel to its face, is moved in a new path, $a_1\,b_1$, as in Fig. 15, such that the lines $c\,d$ and $e\,f$ (drawn parallel to $a_1\,b_1$ and enclosing the blade section) shall be equi-distant from $a_1\,b_1$; then if, for the sake of argument, it be assumed that the normal resistance to a plane moving in a path oblique to its surface is proportional to the sine of the angle of inclination, then the normal stress per square foot due to reaction on the face $g\,e$ would equal the mean of the normal stresses per square foot on the curve $c\,g$. Suppose these represented by $h\,k$ and $h_1\,k_1$ and their components resolved parallel to the screw's axis by $k\,l$ and $k_1\,l_1$, the forward thrust would be $l\,k - l_1\,k_1$, which in such a case as that

* Dr. Froude, in a Note to his paper on "The Elementary Relation between Pitch, Slip, and Propulsive Efficiency," Inst. Naval Architects, 1878.

represented in the diagram would be negative, since $l_1 k_1$ is evidently greater than $l k$. By multiplying these positive and negative unit stresses each by its respective surface it appears as if in this case the negative would be over 60 per cent. of the positive thrust; but, as the variation is not directly with the surface, it would probably considerably exceed this percentage. The diagram is drawn to scale for a section at two feet radius of a screw 10 feet diameter similar to the model *f* and for a slip of 16 per cent. Before edge resistance and the negative thrust consequent upon it could be got rid of for this section of the screw, it would be required to move in the line *g m*, or with a slip of 73 per cent. Of course sections at larger radii, being thinner, offer considerably less edge, but there is to set against this their moving at angles more acute to the direction of rotation than the section shown.

It would thus appear that edge resistance is by no means an item to be neglected in the consideration of a screw's action, and that in many cases where comparatively large screws are applied to vessels, and consequently work with a low percentage of slip, the loss from this cause is probably very great. For example, in the "Iris's" first screws, which worked with an apparent slip so small as to be negative when referred to the mean pitch, so far as can be judged from the screw's sections illustrated in Mr. Wright's paper on that vessel's trials, the central sections of the blades must have been ploughing through the water with a decidedly negative thrust. In Fig. 16, Plate 34, one of the sections is shown. A *b* is the direction of its motion through the water.*

The only available data by which an estimate of the edge resistance of a screw can be made by comparison with the resistance of bodies of similar form appear to be in the now ancient volume, Beaufoy's "Nautical Experiments."

Beaufoy's experiments were made upon bodies wholly immersed and a large number of forms were tried: those which are appropriate to the present purpose are shown in Figs. 17 to 23, Plate 35; the transverse sections of all were rectangular.

These bodies were tried at various speeds from one to eight knots per hour. Their frictional resistances were then estimated from data furnished by independent trials on planks and deducted from the total resistances found by direct experiments. The remainders were what Beaufoy called the "plus" and "minus" resistances, or those due to head and stern.

* This subject, in reference to the "Iris's" trials, is considered by M. Normand in a paper read before the Inst. Naval Architects, 1879.

In his estimates for friction no allowance was made for the variation due to difference in length; and the apparatus with which the experiments were made was far short of the refinements of such establishments as that at Torquay, but the care exercised was such that, with small allowances, the results may be accepted as reliable data, at least until such time as more modern experiments supply better. It is difficult to deduce from Beaufoy's experiments any accurate general law by which the resistance varies with the angle of entrance, but the variation is with the square of the speed, and, for practical purposes, the empirical formula $R = \frac{V^2 \ W \ \text{Sin} \ \theta}{12{\cdot}15}$ in which R is the head resistance in lbs. per foot depth of section, V the velocity in feet per second, W the width in inches of the section measured from the line of motion at widest part and θ the entering angle measured from the line of motion may be used. Properly speaking, R is for an arc bow and an angular run.

Fig. 13, Plate 33, is a diagram by inspection of which the amount of friction may be ascertained quantitively as regards screws of the same pattern as the *c k* series 10 feet diameter when working at 100 revolutions per minute. The total power absorbed in friction, the axial component of that power and the pounds of thrust reduction or drag are given. For other screws of similar patterns but of different dimensions and for other speeds the powers are proportional to the 4·83 powers of the dimensions and to the 2·83 of the speeds, and the thrust reduction is proportional to the 3·83 powers of the diameters and to the 1·83 powers of the speeds.

The preceding may be made the basis of a practical method of calculating the resistance of screws for the propulsion of ships, but, in doing so, it must not be forgotten that a screw propelling a vessel is under very different conditions from a model working in undisturbed water, although the laws of reaction are precisely the same for both. Instead of working in a free stream it works in water which has been put in motion by the vessel. The feed does not flow towards the screw in straight lines parallel to the axis of rotation, but obliquely, laterally and upwards. The screw works in water with a forward motion relatively to the surrounding mass, and the feed has consequently a lower speed than that of the ship. This is equivalent to an increase in efficiency in the proportion of V_1, the speed of advance which the screw would have required with a feed equal to the speed of the ship, to V, the actual speed of advance of the screw.

Again, the feed is drawn away from the stern of the ship, which causes the hydraulic pressure at the stern to be less than it would be if the vessel were towed; which is equivalent to an augmentation of the vessel's resistance. From model experiments Dr. Froude found this to reach 40 and even 50 per cent. of the vessel's own resistance, but the amount depends on the screw's position relatively to the ship. This augmentation of resistance is rapidly reduced by moving the screw astern; and Dr. Froude estimated that, if it could be placed at a distance equal to one-quarter of the ship's beam abaft the stern, the loss from this cause would be reduced to about six or eight per cent.*

The effect of the speed of wake on the screw's performance is generally less marked in twin screw vessels than in those with single screws and they also offer special facilities for lessening the "thrust deduction" as the loss just referred to has been called.

Efficiency of the Screw.—By "efficiency" is not meant efficiency of propulsion which is a different thing and of which the screw's efficiency is an important factor but is only one amongst many. It is the mechanical efficiency or the relation of useful to total work, or, in symbols, if T_w be the total thrust power, F_t the transverse component of the work expended in friction and edge resistance, F_a the axial component of that work, G_w the gross work and V and S speeds of advance and slip, then the efficiency—

$$E = \frac{T_w \frac{V - S}{V} - F_a}{G_w}$$

or since $G_w = T_w + F_t$, $E = \dfrac{T_w \frac{V - S}{V} - F_a}{T_w + F_t} = \dfrac{T_w (V - S) - F_a V}{V (T_w + F_t)}$

Traced out, this equation gives a curve, such as those shown by the line BB in Fig. 24, Plate 36, with a negative ordinate for zero slip. The efficiency rises very rapidly with increase of slip and reaches a maximum height at from 15 to 20 per cent. of slip after which it falls slowly. Screws of the *c k* type, of the three different pitch ratios 1·25, 1·35 and 1·5, whose efficiency curves are drawn in Fig. 24, show little difference in efficiency; but, what difference there is, is in favour of the screw of greater pitch ratio. From this it appears that on the ground of efficiency there is little ground for preference. On the assumption that, by the use of strong material, the section can be so formed as practically to

* See Dr. Froude's paper and discussion thereon, on "Ratio of Effective to Total Indicated Horse Power."—*Inst. Naval Architects*, 1876.

dispense with edge resistance, the set of curves marked A A in Fig. 24, has been drawn; these curves indicate that, especially at low slips, this is a great advantage.

To show the variation of maximum efficiency with pitch ratio more clearly, the curve in Fig. 25, Plate 35, has been drawn, showing the efficiencies for pitch ratios up to 2 for a slip ratio of 20 per cent. This indicates the pitch ratio of maximum efficiency for this design of screw (namely *c k* models), to be somewhere about 1·7, but that its variation for the range of pitch ratios between 1 and 2 is only 8 per cent. In drawing this curve edge resistance has been neglected. It must, however, be clearly understood that these curves refer especially as regards their values to the class of screws for which they are drawn, but that their general characteristics are true for all.

It was stated (under Proposition VI.), that a diagram such as Fig. 7, Plate 28, is sufficient to give the thrust for any slip ratio. This statement was understood to be independent of any consideration of fluid friction or other losses. The effect of these losses is to lower the thrust curve below the line A C and, since edge resistance is greater at lower slips, the curve becomes very concave towards the base for low slip ratios, and ultimately the positive thrust becomes less than the negative thrust and the curve dips below the slip axis, and its ordinates become negative. The form is that of the dotted line D E in Fig. 7.

Efficiency of Propulsion.—Screws are approximately equal in efficiency for a wide range of pitch ratios, and so, for special purposes, almost any pitch ratio within the ordinary limits of practice may be chosen as giving efficiency practically equal to any other, but, generally, certain principles point clearly in one direction for the determination of the most suitable screw.

In designing the propelling machinery for any vessel, there is one main object to be kept in view, viz., economy.

This may be referable to propelling the vessel at a given speed at the lowest possible cost; a consideration involving the current working expenses such as the costs of coal, stores, repairs, attendance, interest on capital invested, insurance, and of carrying the machinery, coal and other stores as cargo (because if, by any reduction in weight of machinery or stores, more cargo could be carried it would bring in a return as an increase in interest); this is again dependent on the relative costs of machinery, coal, stores, repairs, labour and freight, which again depend on temporary conditions of the market, the length of voyage and the vessel's trading area; but, these conditions being known, the problem is

one which admits of an approximate solution; in its entirety it is out of the scope of the present paper but the general tendencies can be indicated: or,

The economy may be referable only to the standard of weight; this admits of a much simpler solution.

It is clear that, all else being equal,—

The total weights and cost of the machinery and of coal used vary inversely with the screw's efficiency;

The weight and cost of the engine vary inversely with the revolutions;

The revolutions increase with decrease of pitch ratio;

The diameter of the screw decreases with increase of slip;

The revolutions increase with decrease of the diameter of the screw and with increase of the slip ratio; and, therefore,

The weight and cost of the engine decrease with increase of slip and with decrease of pitch ratio.

Commencing with a screw of maximum efficiency with the object of augmenting propulsive economy, it is necessary to decrease the pitch and increase the slip ratios. Consequent on such modification the weight and cost of the boilers and fuel will be increased and the weight and cost of the engines decreased. For weight economy there will be an advantage so long as, for small variations in the screw's proportions, the increments of the weight of boilers and fuel are less than the decrements of the weight of the engines; but, when that point is reached, when, for small variations of the screw's proportions, the increments and decrements of the said weights are equal to each other, the maximum of economy has been attained. The same principle holds with regard to economy of cost, but the increments and decrements of the costs must be studied in place of the weights only.

The following example will illustrate the principle for weight economy:—

Total weight of machinery &c.		800 tons.
Indicated horse-power		8,000
Consumption per I.H.P. per hour		2·25 lbs.
Screw	Pitch ratio	1·30
	Slip ratio	0·13
	Efficiency	0·60
	Form similar to *c k* series	

Weights of machinery distributed as follows:—

Engines, &c.	0·375	of total
Boilers, &c.	0·525	
Constant	0·100	

The following tabular statement illustrates the variation of the weights with the slip ratio and, assuming that the difference is made up in fuel, the effect upon the steaming endurance of the vessel.

TABLE XV.

Slip per cent.	Efficiency of Screw.	Diameter of Screw.	Revolutions.	Ratios of Weights.				Total Weight in Tons.	Increased			Ratio of Wetted Surface to Disc Area.
				Engines.	Boilers.	Constant.	Total.		Fuel Weight in Tons.	Steaming Endurance.		
										Hours.	Knots at 18 per Hour.	
13	0·600	1·000	1·000	0·375	0·525	0·100	1·000	800	...	...	...	36·0
15	0·624	0·906	1·145	0·315	0·505	0·100	0·920	736	64	8·275	149·00	43·8
20	0·640	0·706	1·552	0·234	0·492	0·100	0 826	661	139	18·410	331·50	72·2
25	0·635	0·579	2·000	0·177	0·497	0·100	0·774	619	189	24·860	447·10	107·5
30	0·620	0·497	2·514	0·144	0·508	0·100	0·752	602	198	25·410	457·10	145·5

Since the date of the "Iris's" trials, when the fact that large screws and efficiency of propulsion did not go hand in hand was so forcibly demonstrated, the relative diameters of screws in this class of vessels have been rapidly reduced, until, in the case of H.M.S. "Howe," the screw's disc area was only about $\frac{1}{8}\frac{1}{2}$nd of the wetted skin (which is an approach to the proportion adopted in ordinary cargo steamers) as against about double that proportion in the case of the "Iris's" smaller screws.* It would appear from the calculation whose results have just been given in Table No. XV., which is not quite a hypothetical case, that the ratio might be still further reduced with increase in weight economy. (See Fig. 26, Plate 37.) This saving in weight of machinery might be applied to increase the armament in the case of war vessels or, as in the illustration, to increasing the steaming endurance of the vessel, but, concurrently with this improvement, there ought to be also an economy in first cost with reduction of weight.

Other important points might be discussed, but having attempted to place certain facts respecting a screw's reaction in a clearer light and to lift others out of much obscurity to more certain ground and having indicated very briefly what method of applying these facts is, in the writer's opinion, calculated to secure greater economy of propulsion, it were well to close a paper which has already far exceeded the bounds prescribed by prudence.

* This statement is made without involving the general assumption that a ship's resistance is proportional to its wetted surface. It is used as a convenient comparison between similar vessels.

In conclusion, the writer must express his hearty thanks to Mr. F. C. Marshall for having fully placed at his disposal the experimental data possessed by the Messrs. R. & W. Hawthorn, Leslie & Co., Limited, for the purpose of this paper, and further for having given him the use of the experimental apparatus in order that the further trials whose results are now embodied in the paper might be made.

APPENDIX.

1.—Fluid Friction on Blades.

The most reliable data on the subject of fluid friction are to be found in the late Dr. Froude's paper on "Surface Friction," published in 1872. It is a report of his own experiments made with boards of various lengths from 6 inches to 50 feet, and with surfaces of various kinds. Of these Hay's composition, varnish and tinfoil were the most important.

These experiments show that the frictional resistance per square foot of surface decreases with increase of the length of surface and appears to approach a limiting value with increase of length. With Hay's composition and varnish it varied with the 1·83 power of the velocity for all the lengths of surface experimented upon, but, with short surfaces of tinfoil the variation was with some power of the velocity higher than the square. For surfaces varnished or coated with Hay's composition the co-efficients, or the resistances per square foot of surface moving at a velocity of 1 foot per second, are as follows :—

Length of Surface	50	16	5	2·5	1·5 feet.
Co-efficient of Friction	0·00596	0·00672	0·0088	0·00997	0·0104 lbs.

These co-efficients appear higher than those usually given but the reductions have been made on the 1·83 powers of the velocities and the squares of the velocities are usually taken on the incorrect assumption that they are practically the same.

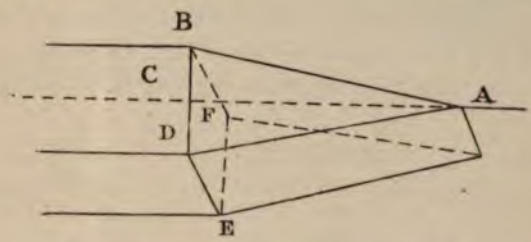
The co-efficients for tinfoil surfaces appear to be considerably less (in some cases 30 per cent.) than those for varnished surfaces in short planks at speeds about 600 feet per minute, but, by their rapid increase with velocity, the former tend to overtake the latter at higher speeds.

Colonel Beaufoy's experiments made in 1798 showed that for the condition and lengths of surfaces he tried, the resistance varied with the 1·75 power of the velocity, the co-efficient for long planks being 0·0049.

The frictional co-efficients for varnished surfaces of any length between 1·5 and 10 feet may be found from Fig. 12, Plate 32, which has been constructed from Dr. Froude's data.

2.—Edge Resistance.

In the following Table the head resistances of wedge-shaped bodies, from Beaufoy's experiments, are compared with $\sqrt{\sin\theta\cos\theta}$, in which θ is this angle of incidence B A C.



The resistances are for the whole section B D E F which was in all cases 1 foot square.

θ	Head Resistances at 8 Knots, lbs.	Sin θ	Cos θ	$\sqrt{\sin\theta\cos\theta}$	Ratios.		Calculated Resistances.
					Resistances.	$\sqrt{\sin\theta\cos\theta}$	
9° 44′ 10″	30·67	0·1691	0·9856	0·408	1·000	1·000	30·35
14° 28′ 40″	35·34	0·2500	0·9682	0·492	1·152	1·205	36·60
19° 28′ 15″	41·71	0·3333	0·9428	0·561	1·361	1·375	41·70
30° 0′ 0″	51·44	0·5000	0·8660	0·658	1·678	1·613	49·00

In the last column the resistances are calculated from $R = 1{\cdot}161\ V^2 S \sqrt{\sin\theta\cos\theta}$, V being the speed in knots and S the section in square feet. It is probable that the resistance does not vary exactly with the width in bodies of different dimensions though this has been assumed.

For the sum of head and stern resistances of bodies with similar ends, the variation with the angle is in a higher ratio than for the head resistances alone, as estimated from Beaufoy's data and given above. The sums are given in the Table below.

θ	Sum of Plus and Minus Resistances, lbs.	Ratio of Resistances.	Ratio of Sines.
9° 44′ 10″	32·13	1·00	1·00
14° 28′ 46″	45·62	1·42	1·48
19° 28′ 15″	56·90	1·77	1·97
30° 0′ 0″	90·38	2·81	2·96

As small angles have to be dealt with in screws (generally under 13°), probably it is sufficiently accurate for practical purposes to assume that the resistance varies as the sine of the angle of incidence for the sum of plus and minus pressures.

An examination of the resistances of the bodies A *a*, B *a* and A *b* is interesting. Both the ends of A *a* are alike, the forward end of *b* A and the after end of B *a* are similar to those of A *a*, but the ends B and *b* are formed of arcs containing the same angle as A. The results are as follows:—

Body.	Sum of Head and Stern Resistances.	Direction of Motion.
A *a*	32·13 lbs.	With arrow.
b A	30·49 „	Against „
A *b*	32·80 „	With „

the curved entering and angular following edge having the smallest resistance. The forms of the bodies referred to are shown in Figs. 17 and 18, Plate 35.

The PRESIDENT said, as the evening was now very far advanced, and as there were several gentlemen who wished to take part in the discussion upon the paper, he thought it would be better to adjourn the meeting.

Mr. B. G. NICHOL moved, and Mr. CHARLTON seconded, that the meeting be adjourned until that night fortnight.

Mr. WEIGHTON said, if the discussion was to be adjourned for a fortnight, it would be only fair that the members should have copies of the paper and diagrams by that time.

The SECRETARY said that in accordance with Bye-law 36, any member who had wished to receive a copy of the paper before its being read, could have had such by writing to him. He feared the diagrams could not be got ready in a fortnight, but he would see what could be done.

Mr. ARTHUR LAING said the diagrams were the most useful part of the paper.

The PRESIDENT asked if it would not be better to leave the matter in the hands of the Secretary?

Mr. ARTHUR LAING said he still thought they ought to adjourn till such time as they could discuss it properly.

Mr. WEIGHTON said that the paper should be printed with all the diagrams, even should the meeting be put off further. This on being put to the meeting was carried.

To illustrate Mr Blechynden's paper on "The Reaction and Efficiency of the Screw Propeller"

TESTING TANK FOR MODEL SCREWS.

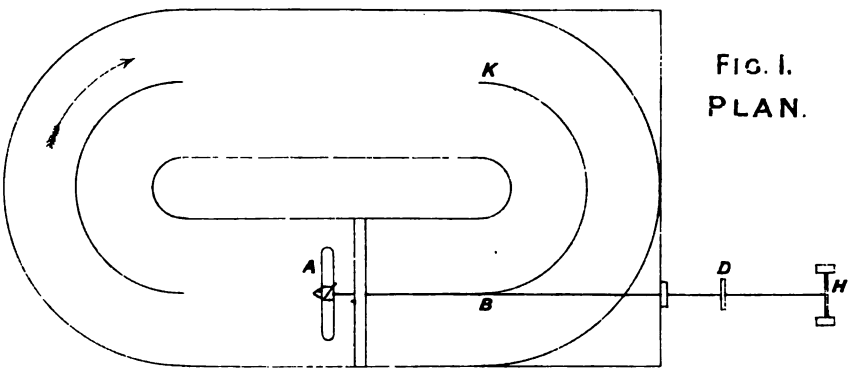
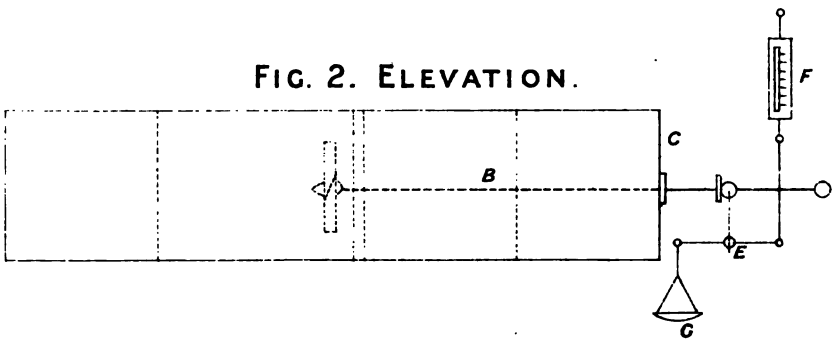


FIG. 1.
PLAN.

FIG. 2. ELEVATION.



A. Screw.

B. Screw spindle.

C. Lightly packed gland.

D. Thrust flange.

E. Bell crank with fork end and antifriction wheels.

F. Spring balance with vernier.

G. Scale pan for heavier weights.

H. Crosshead with antifriction rollers on ends to gear into driving shaft.

K. Guide plate.

Ant. Rusch, Lith. Newcastle

To illustrate Mr Blechynden's paper on

FIG. 5.

BLADE. *p*

FIG. 3.

BLADES *a & b* ___
BLADE *o* ----

FIG. 7.

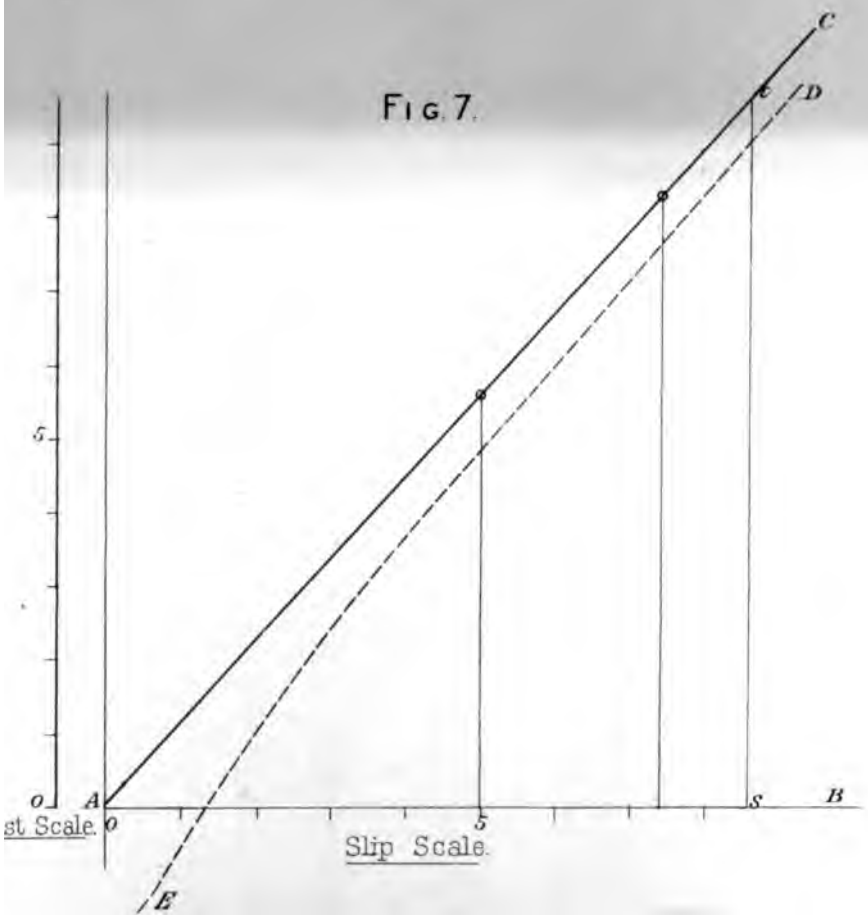


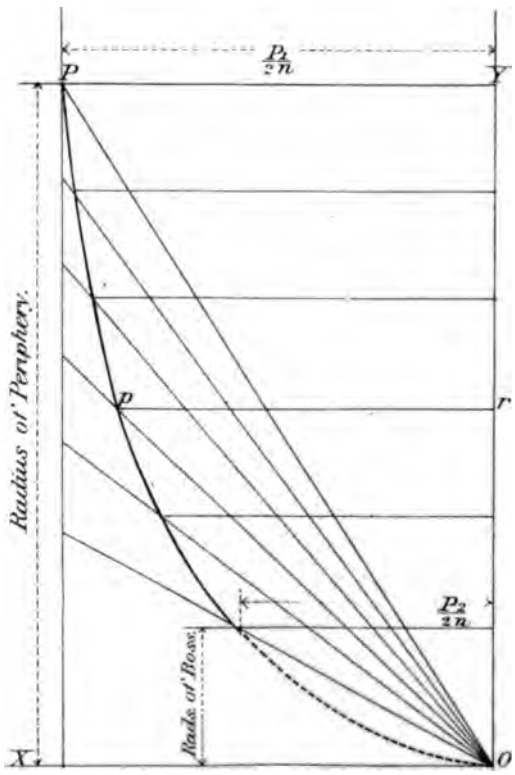
FIG. 4.

BLADE. *c. k.* SERIES

FIG. 6.

BLADE. *g.*

FIG. 11.



P_1 pitch at periphe
P_2 " " boss
OY centre line of
OX axis of Screw

To illustrate Mr Blechynden's paper on

FIG. 5.

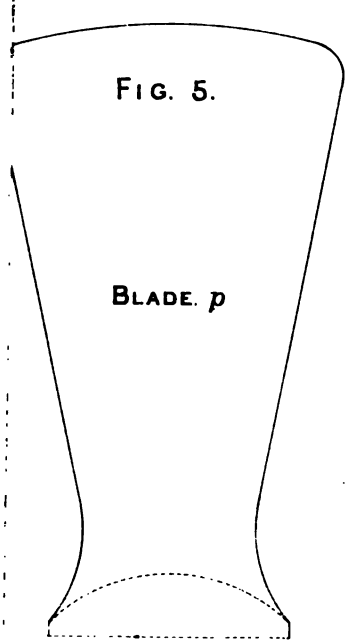


FIG. 3.

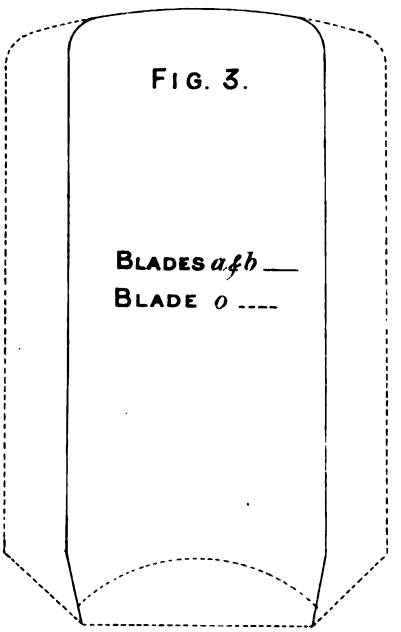
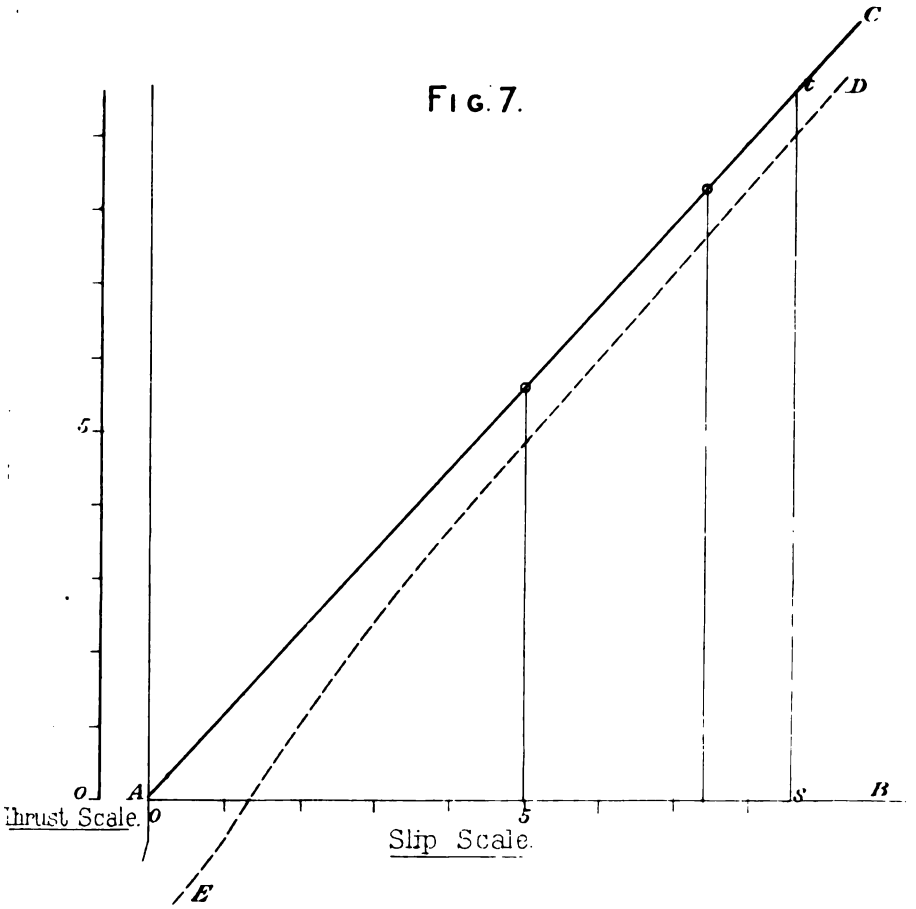
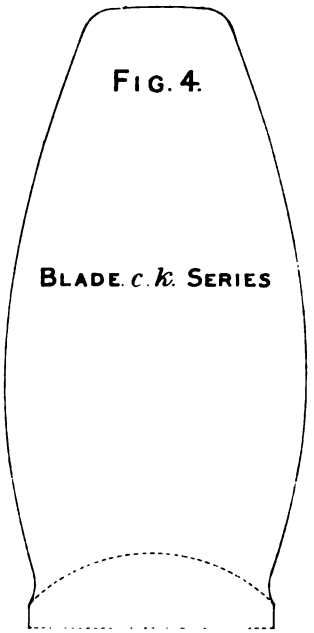
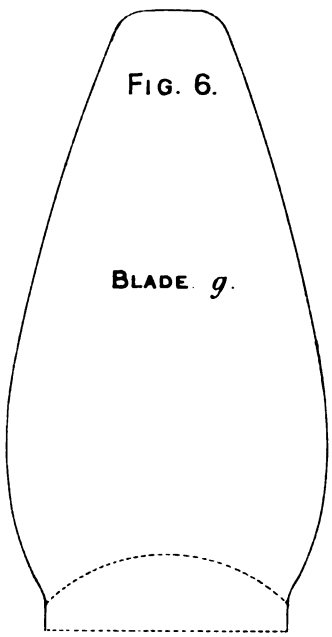


FIG. 7.







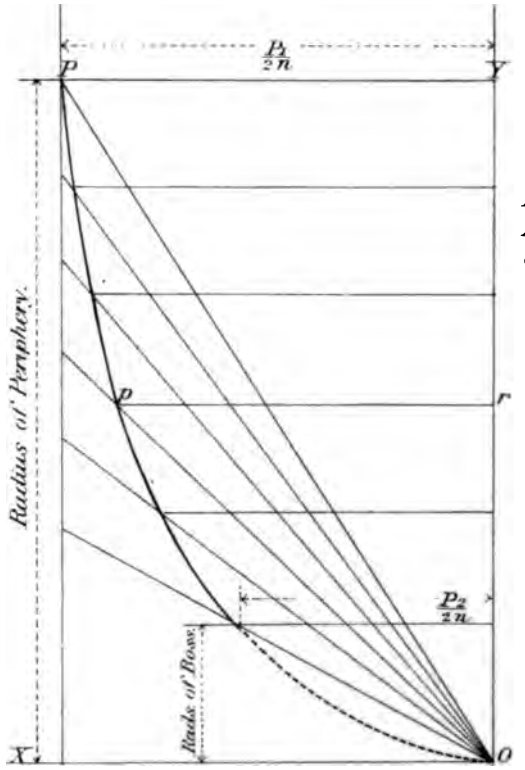
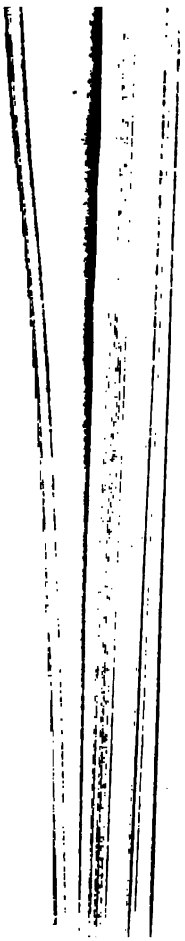
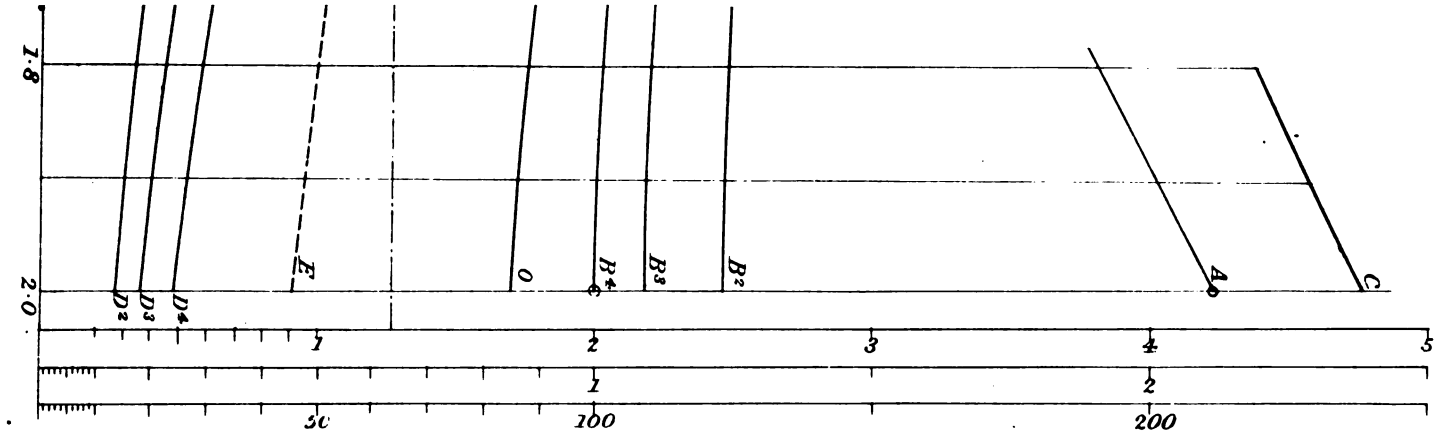


FIG. 11.

P_1 pitch at periphery
P_2 " " boss
OY centre line of S
OX axis of Screw





Scales for:
A.A.
C.C. and D.D
B.B.

And Read, Joh Newcastle.

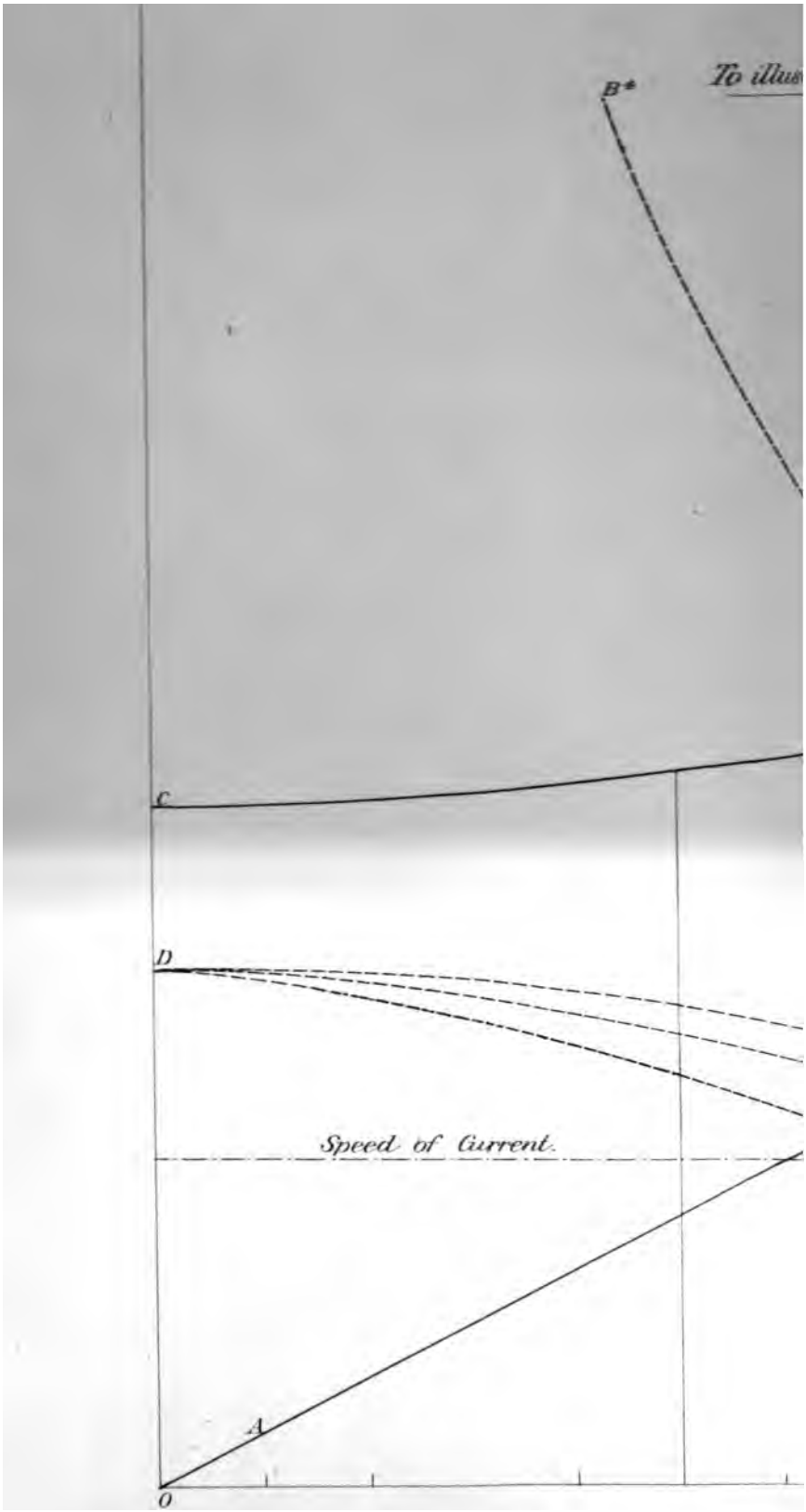
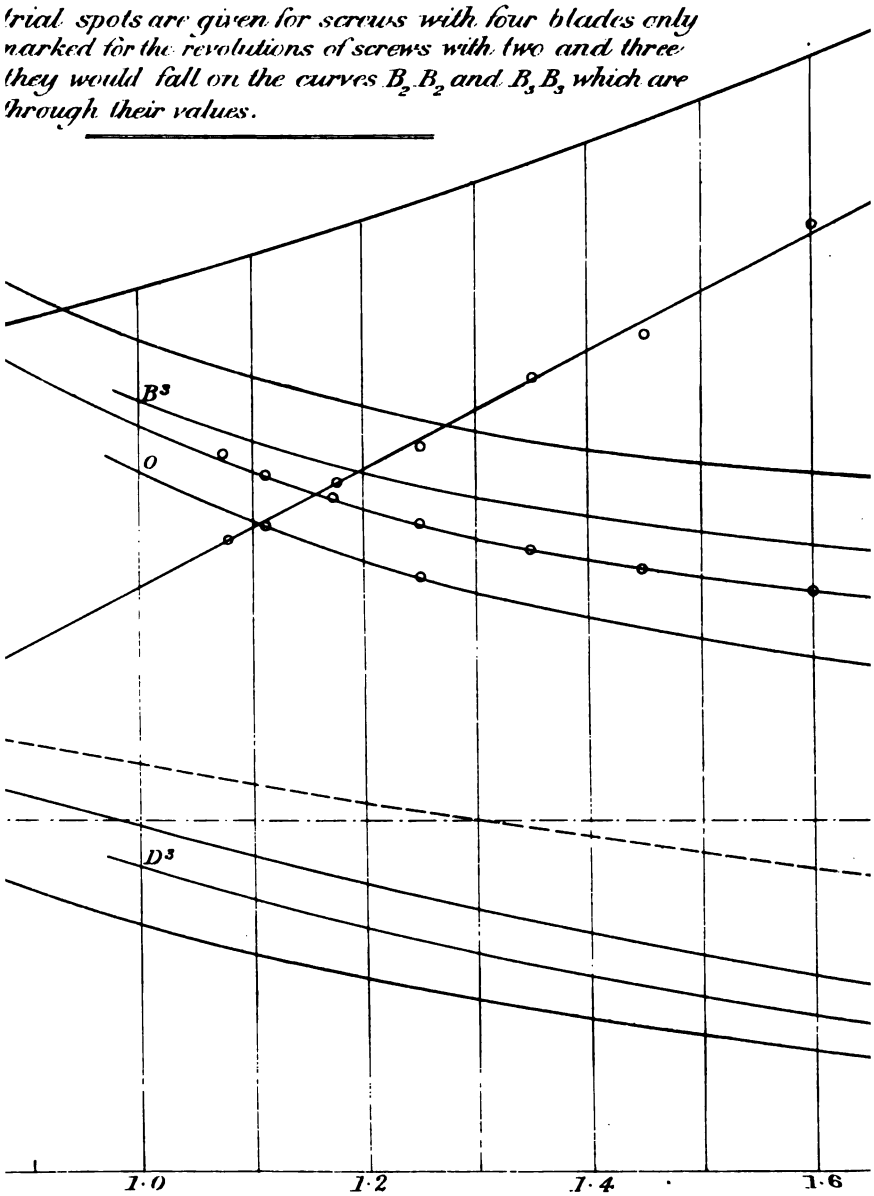

To illus
B*
C
D
Speed of Current.
A
O

FIG. 10.

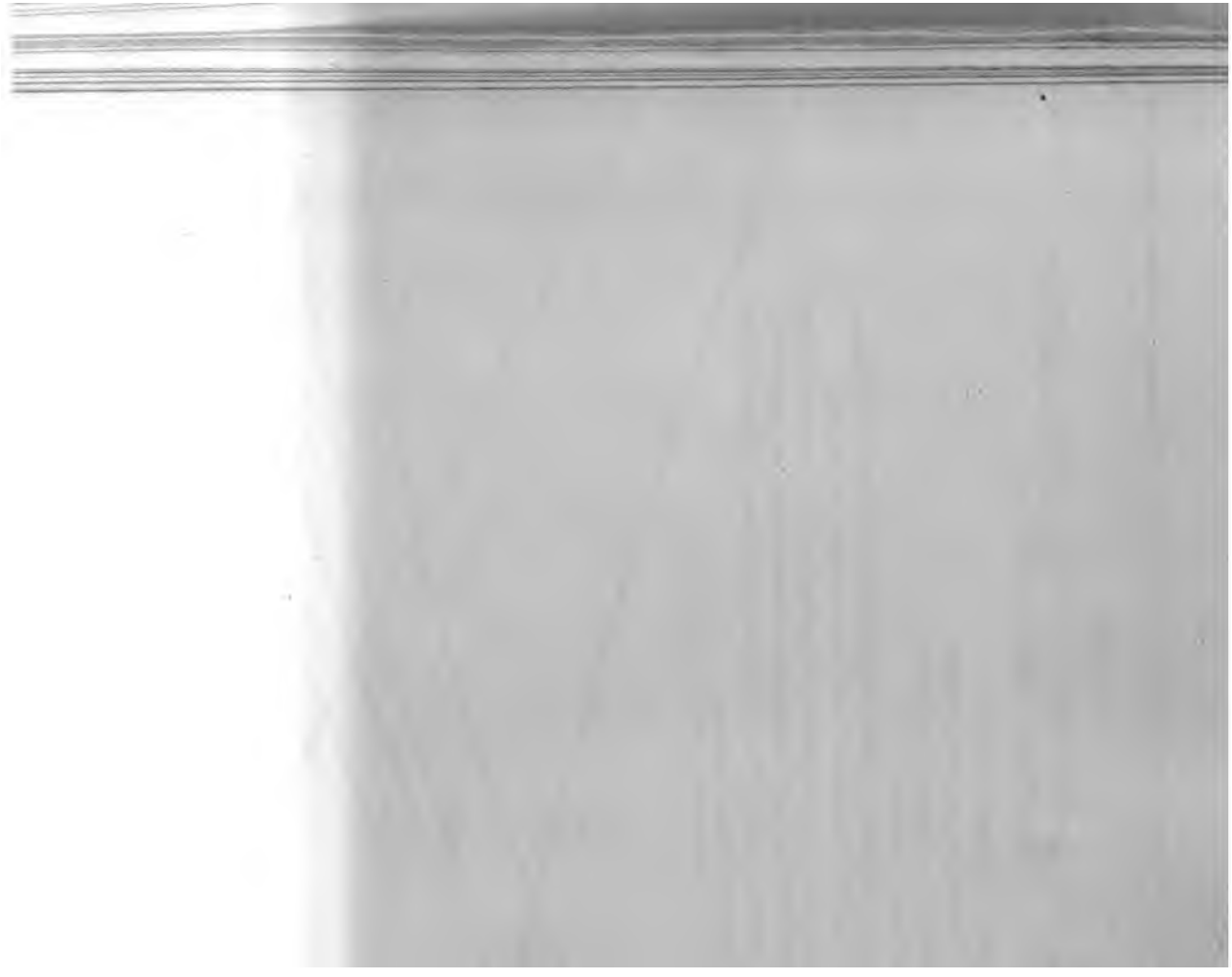
OF EXPERIMENTS WITH MODEL SCREWS

(CONSTANT THRUST 5·6 LBS.)

tive Weights in lbs.
Revolutions per minute
vance of screw in knots
duli or values of C
sival limit of modulus for 0·25 slip ratio (Rankine)
suffix numbers indicate number of blades
trial spots are given for screws with four blades only
narked for the revolutions of screws with two and three
they would fall on the curves $B_2 B_2$ and $B_3 B_3$ which are
hrough their values.



Pitch Ratio.



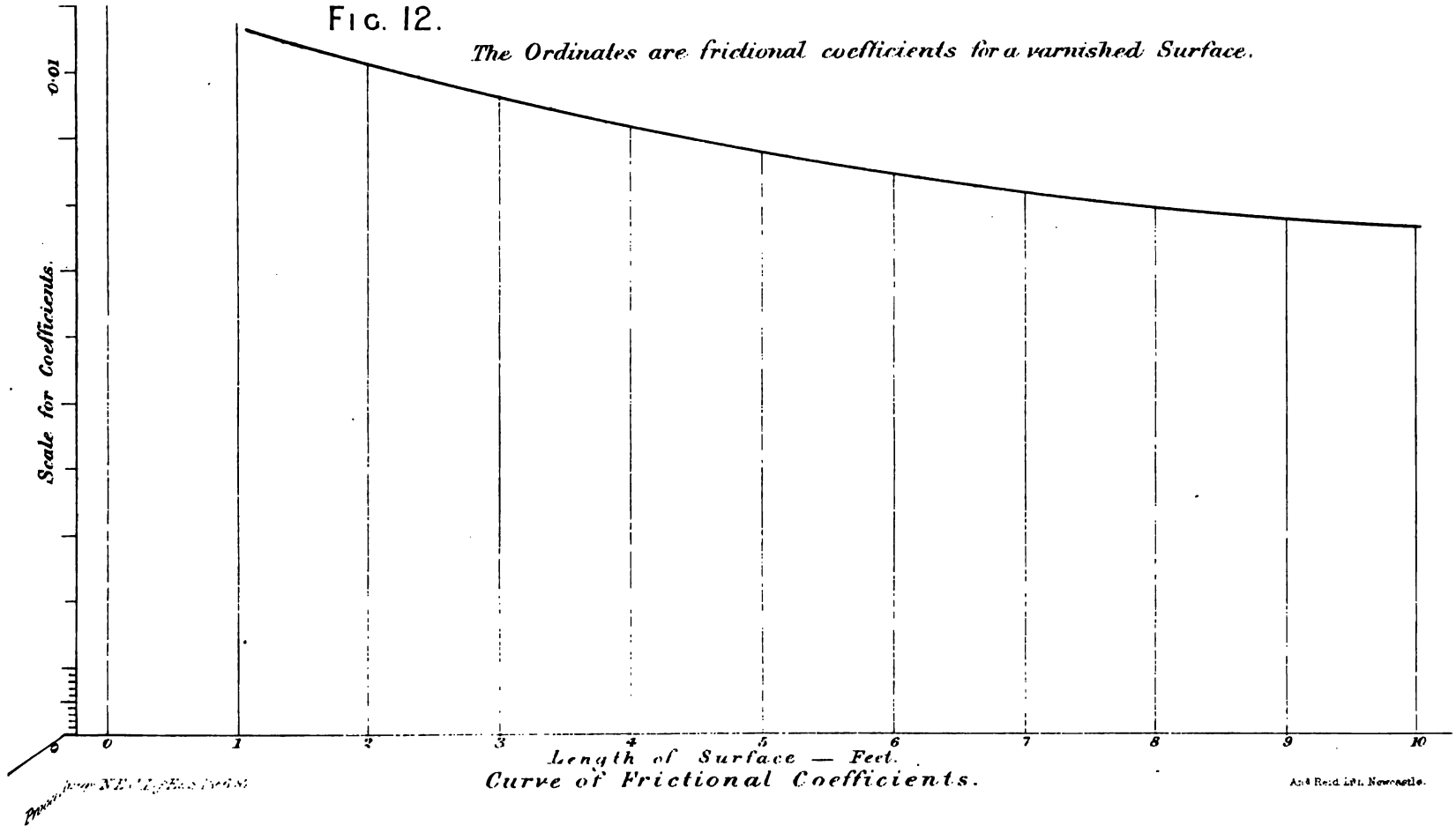
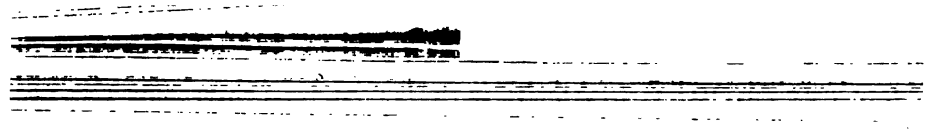


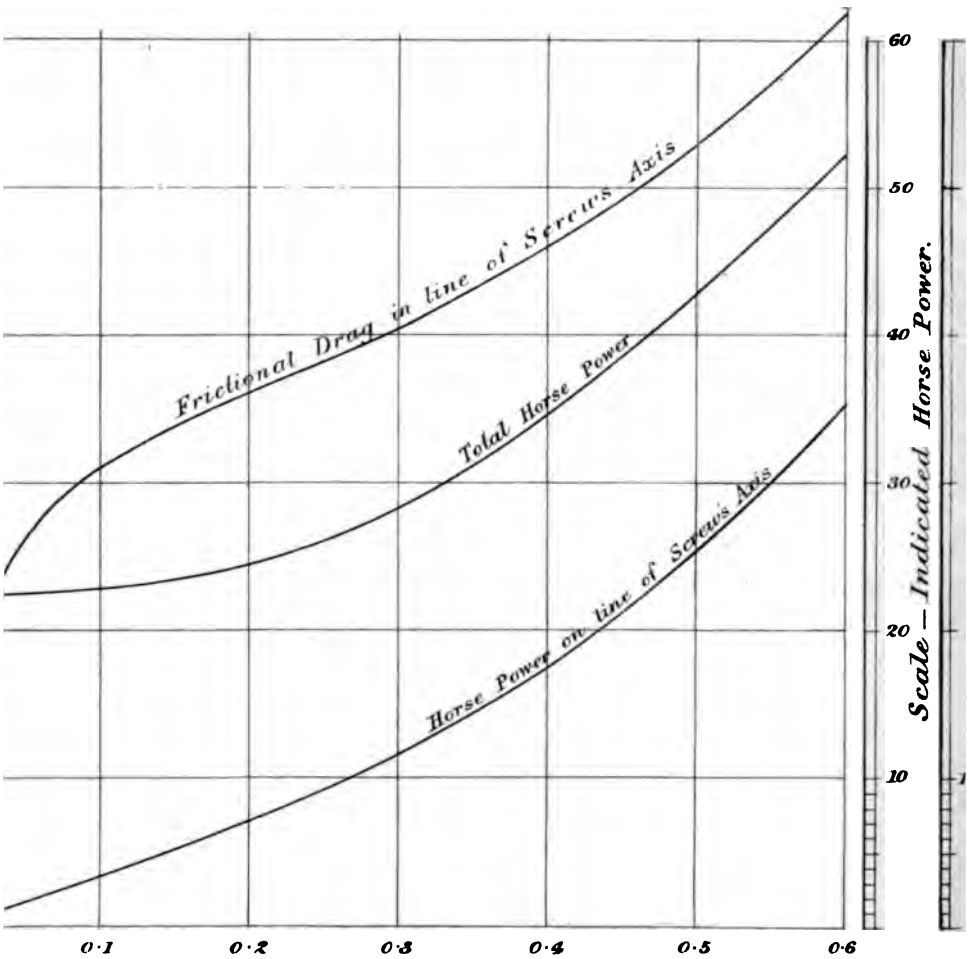
FIG. 12.
The Ordinates are frictional coefficients for a varnished Surface.
0·01
Scale for Coefficients.
0
1
2
3
4
5
6
7
8
9
10
Length of Surface — Feet.
Curve of Frictional Coefficients.



illustrate M.r Blechynden's paper on "The Reaction and Efficiency of the Screw Propeller"

FIG. 13.

DIAGRAM OF POWER ABSORBED IN FRICTION.



(1–Slip ratio) × Pitch ÷ Circumference.

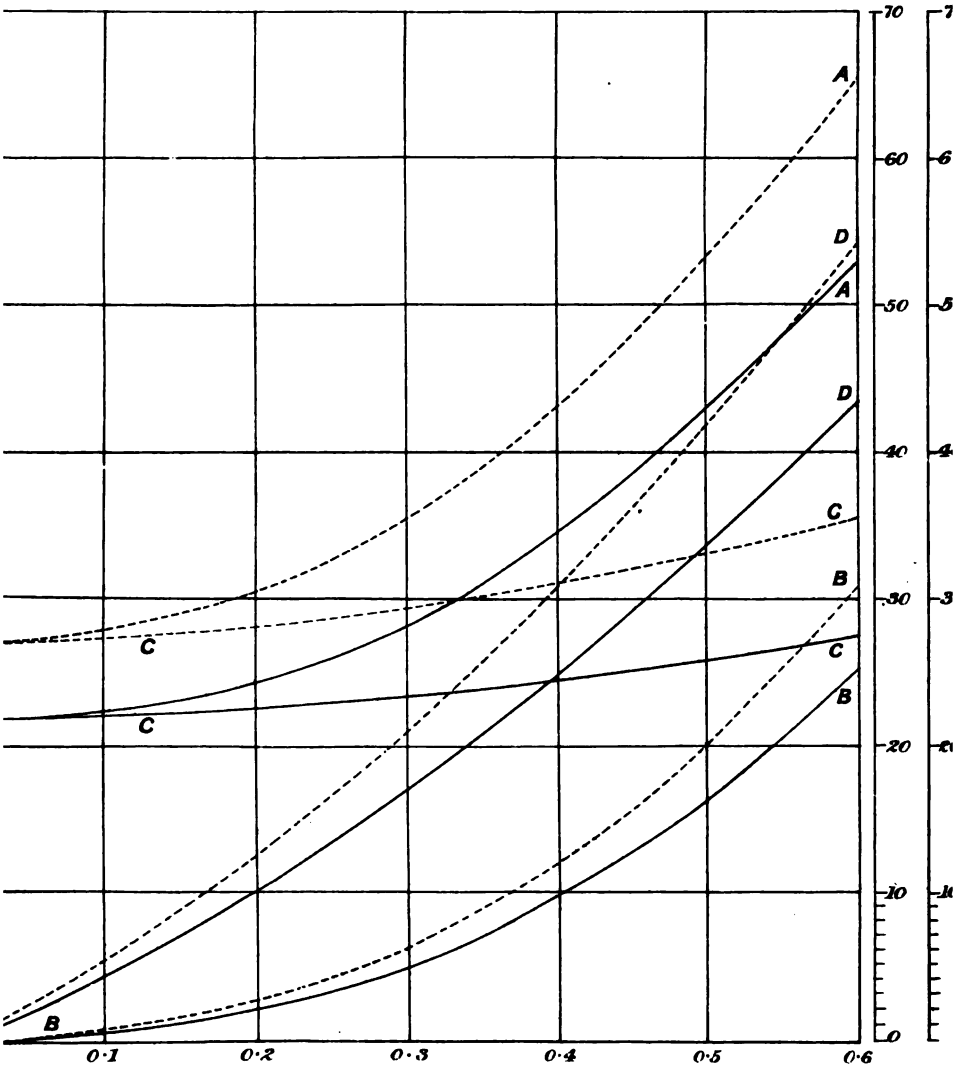
To illustrate Mr Blechynden's paper on "The Reaction and Efficiency of the Screw Propeller."

FIG. 13.

DIAGRAM OF POWER EXPENDED IN FRICTION.

AA Total Horse Power.
BB Horse Power in the direction of the Screws axis.
CC Horse Power in transverse direction.
DD Frictional drag in the direction of the Screws axis.

The full lines are for frictional coefficient of '01, the dotted lines for a coefficient of '0125, probably more nearly correct for ordinary screws. The dotted lines have been used in calculating the approximate efficiencies of curves. Figs 24 & 25.



(1-Slip ratio) x Pitch ÷ Circumference.

To illustrate Mr Blechynden's paper on "The Reaction and Efficiency of the Screw Propeller"

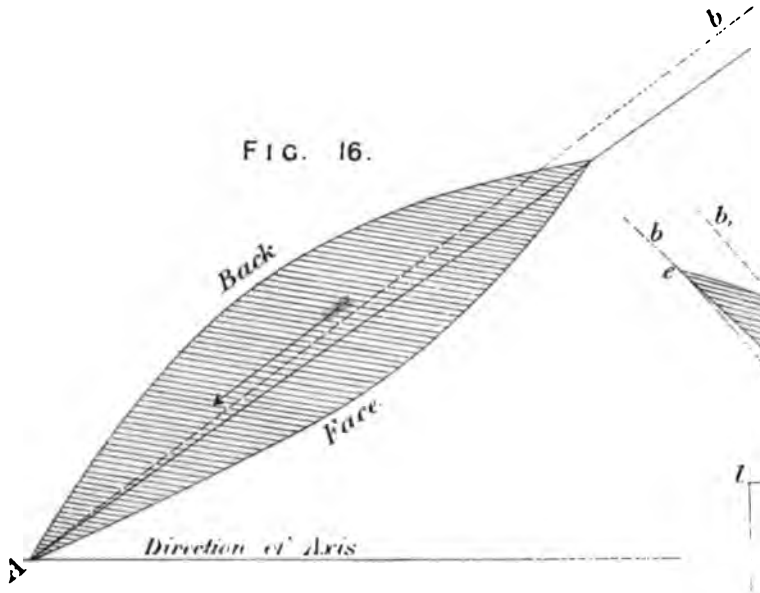


FIG. 16.

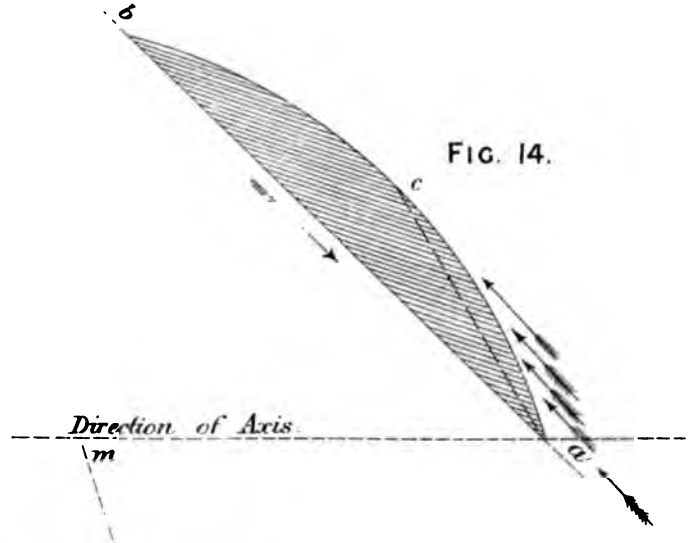


FIG. 14.

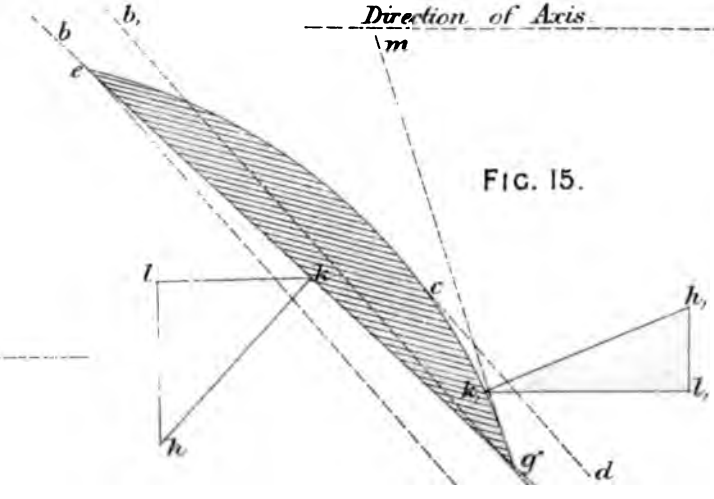
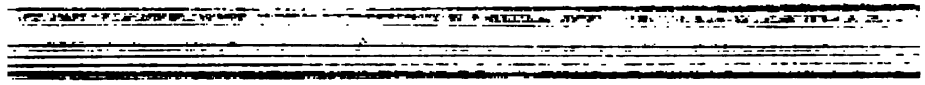


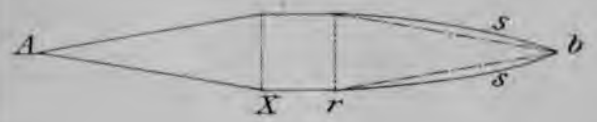
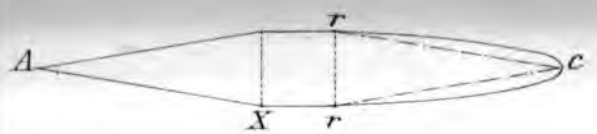
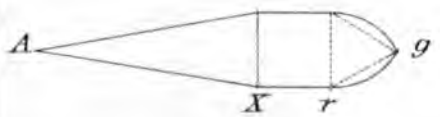
FIG. 15.



To illustrate Mr Blechynden's paper

PLANS OF BODIES EXPERIMENTED UPON

The immersed Section of each of the bodies is a squ
side is one foot. Each body was tried moving
direction of the arrow and also in the oppos

Fig		
№17.		*o XA-3·0 X*
№18		*AX-3·0 X*
№18		*AX-rb-3·* *rs Segme* *sb tange*
№20		*AX-rc-3·* *rcr-semi*
№21		*AX-3·0*
№22		*AX-3·0*
№23		*AX-3·0* *rg circul*

and Efficiency of the Screw Propeller"

Y.

Rads.

dius

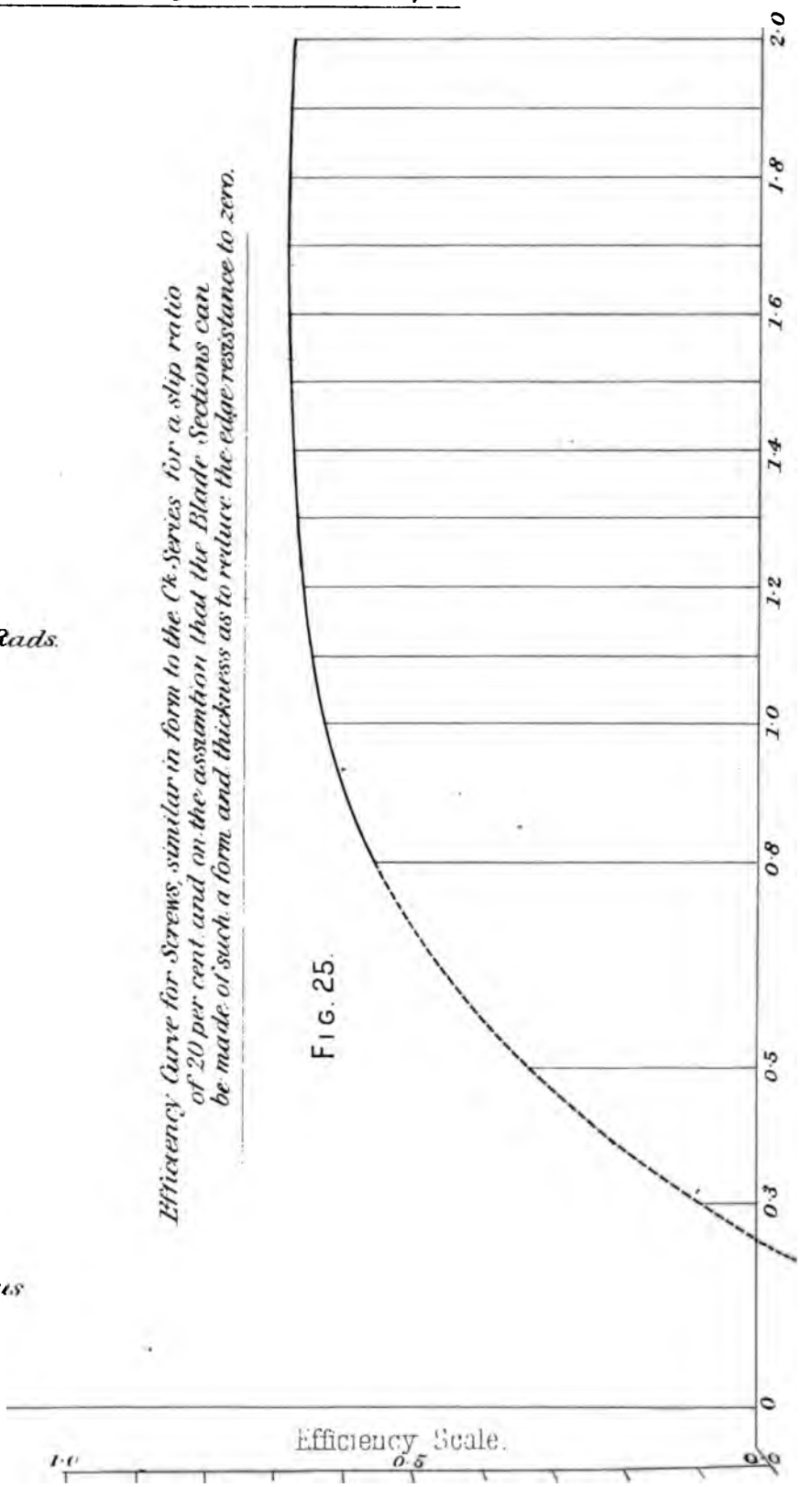
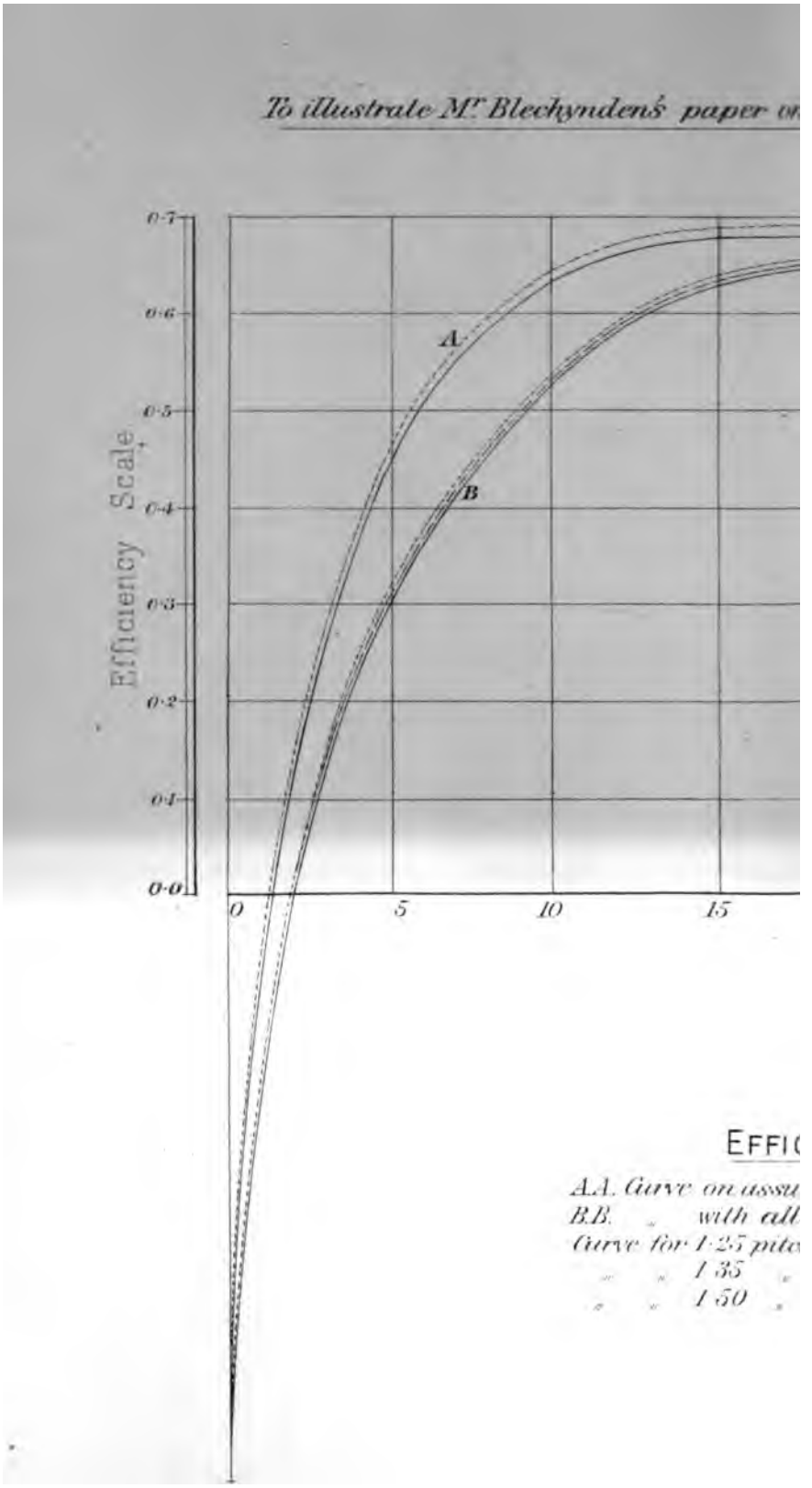
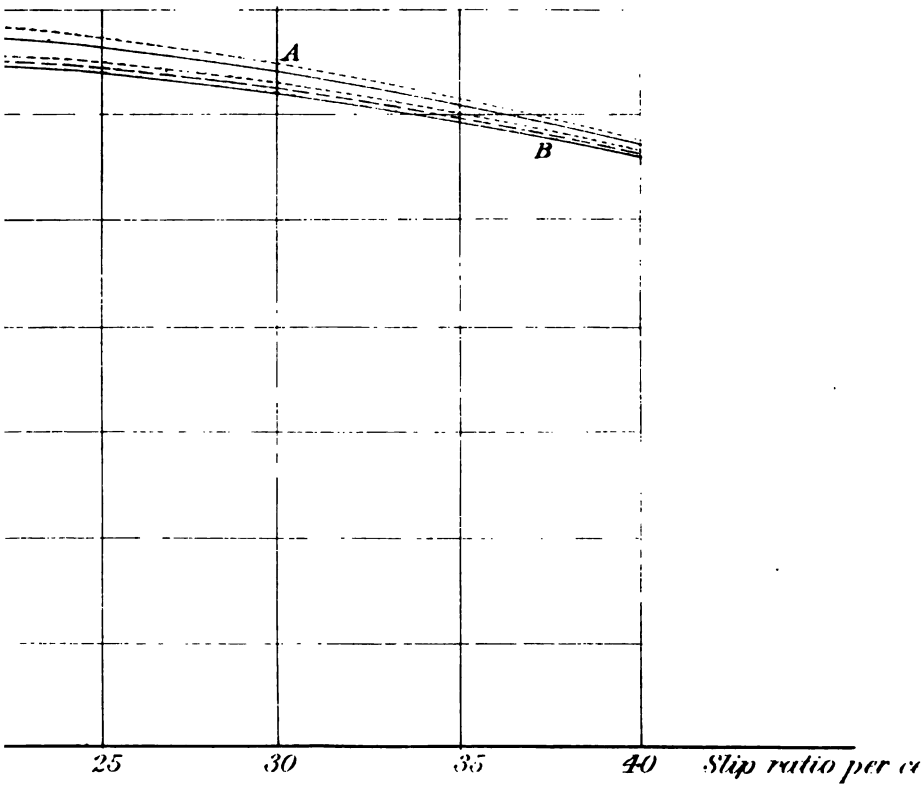


FIG. 25.

Efficiency Curve for Screws similar in form to the Ck Series for a slip ratio of 20 per cent. and on the assumption that the Blade Sections can be made of such a form and thickness as to reduce the edge resistance to zero.


To illustrate Mr Blechynden's paper
Efficiency Scale
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0·0
A
B
0
5
10
15
EFFI
A.A. Curve on assu
B.B. " with all
Curve for 1·25 pito
" " 1·35 "
" " 1·50 "

ion and Efficiency of the Screw Propeller"



RVE.

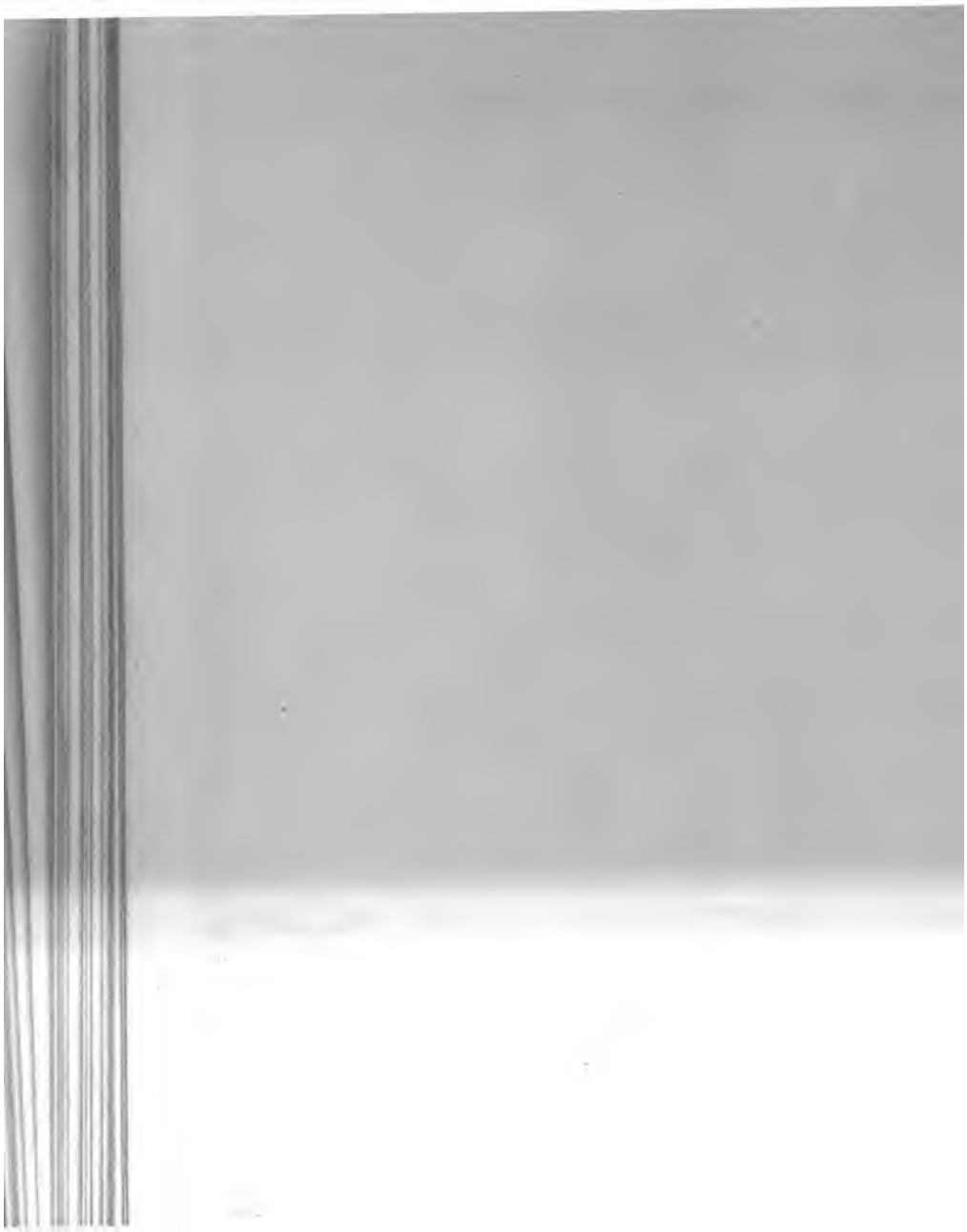
edge resistance is nil

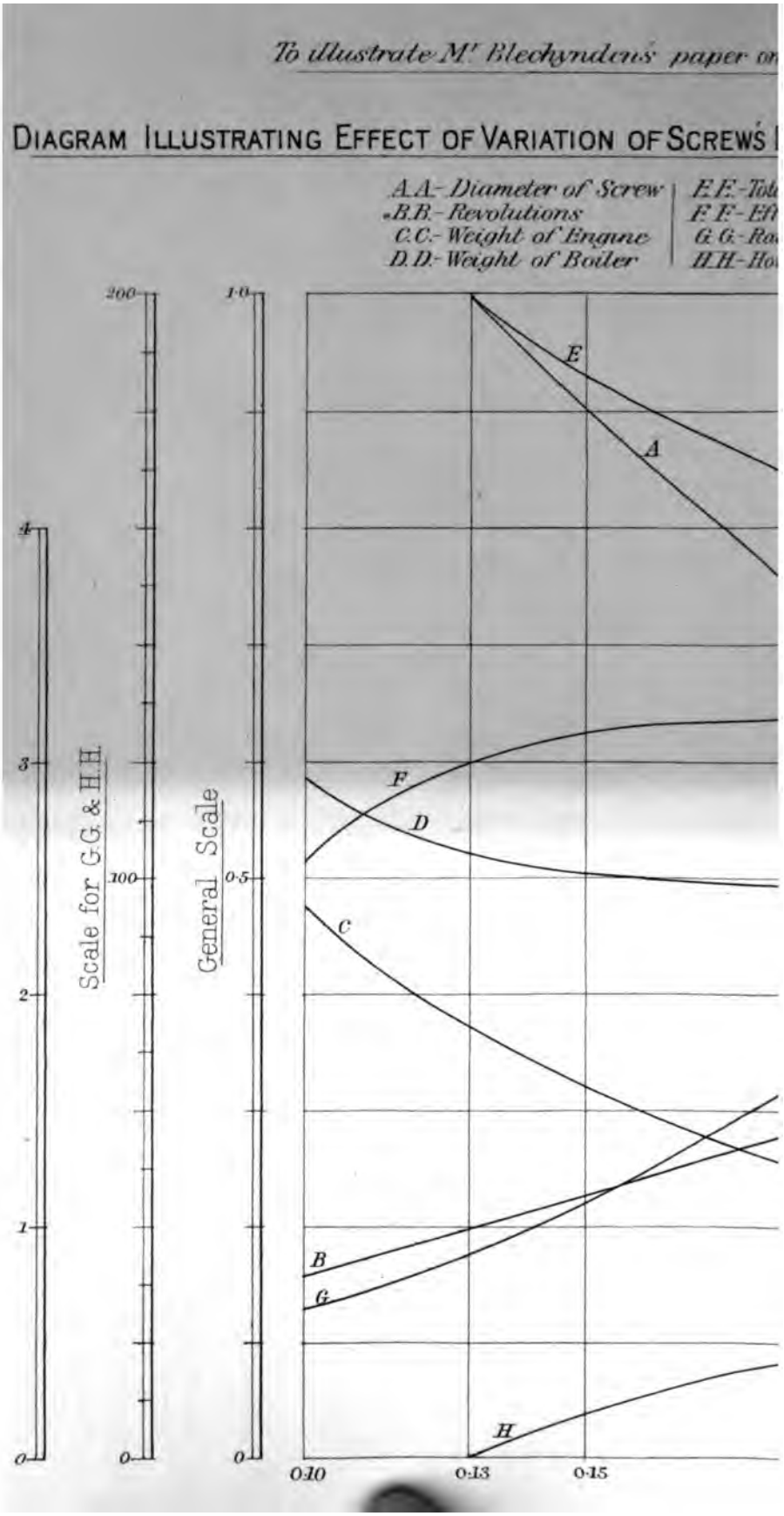
thus ——— . — . — —

" — — — — —

" - - - - - - - - - - - - - -

And Bell & Loth, Newcastle.



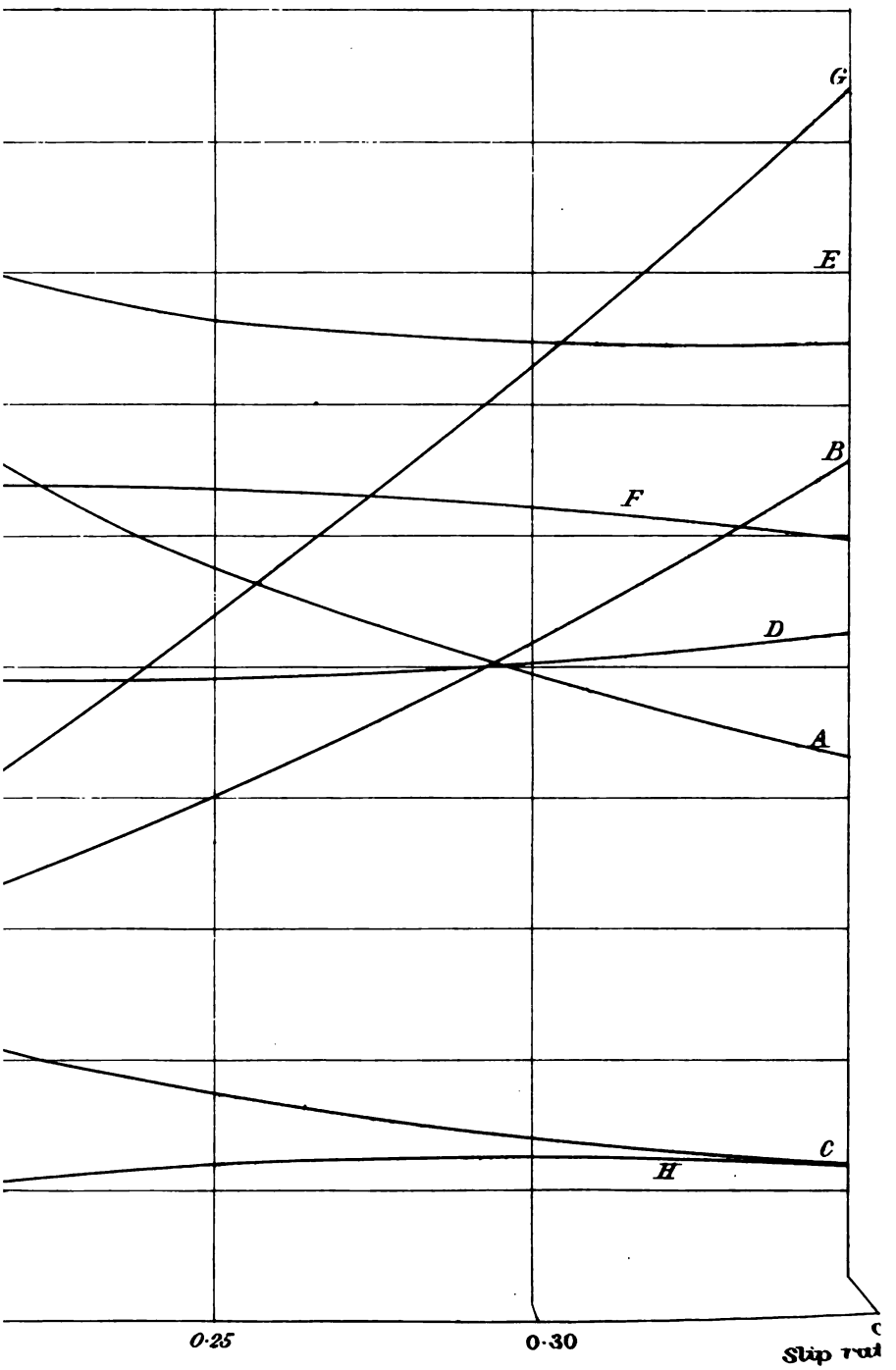

To illustrate M^r Blechynden's paper on
DIAGRAM ILLUSTRATING EFFECT OF VARIATION OF SCREWS
A.A.- Diameter of Screw
B.B.- Revolutions
C.C.- Weight of Engine
D.D.- Weight of Boiler
E.E.- Tot
F.F.- Ef
G.G.- Ra
H.H.- Ho
200
100
0
4
3
2
1
0
Scale for G.G. & H.H.
1·0
0·5
0
General Scale
E
A
F
D
C
B
G
H
0·10
0·13
0·15

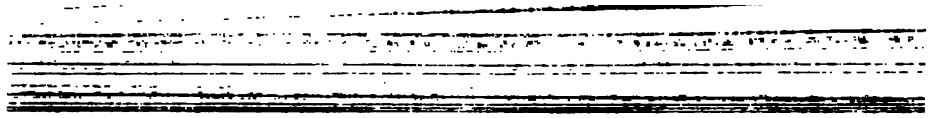
n and Efficiency of the Screw Propeller"

GHTS OF MACHINERY & STEAMING ENDURANCE OF VESSEL

achinery = wt. Engine + wt. Boiler + 1

face to disc area
eaming endurance





NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886–87.

PROCEEDINGS.

SEVENTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON WEDNESDAY EVENING, APRIL 6TH, 1887.

F. C. MARSHALL, ESQ., VICE-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the last general meeting, held in Newcastle-upon-Tyne, on March 9th, which were approved by the members present, and signed by the Vice-President.

The VICE-PRESIDENT said, with reference to the second article on the agenda, he might say that he had the pleasure of being present at the meeting of the Council of the Institution of Naval Architects in London last week when their letter of invitation to that Institution was read, and an answer arranged to be sent to their Institution, and he would like to say that the invitation was received by the President (Lord Ravensworth) and the Council in a most hearty manner. He believed there would be a very large meeting of the Institution of Naval Architects, and which he had no doubt would be exceedingly interesting, but he need not say that a very large amount of that interest would depend upon the papers that were read. They could show their friends from the other parts of the country very many interesting objects in the shape of works, shipbuilding yards, vessels under construction, etc., but the important part of the meeting, he respectfully submitted to them, would depend

upon the papers produced at the morning meetings, of which there would be four. Lord Ravensworth had hinted to him that they should not have more than two papers each morning, and he was urged to do his best to induce the President and members of this Institution generally to see that the papers were produced from their Institution. He was sure the President—who unfortunately was absent that night—and the Council would be very much indebted to them if they would endeavour to make the request of the Council of the Institution of Naval Architects known, and one and all make an effort to produce the eight papers—or a fewer number—for those meetings. He was quite sure that there was talent enough on their rivers to produce papers on practical subjects that would be of special interest to the Naval Architects at their meeting, and elicit discussion which would answer the purpose the Institution had in visiting their locality. He would now call upon the Secretary to read the letter received from the Council of the Institution of Naval Architects.

INSTITUTION OF NAVAL ARCHITECTS,
5, ADELPHI TERRACE, LONDON, W.C.,
Wednesday, March 16th, 1887.

TO THE PRESIDENT
OF THE NORTH-EAST COAST INSTITUTION
OF ENGINEERS AND SHIPBUILDERS,
NEWCASTLE-UPON-TYNE.

DEAR SIR,

I have much pleasure in informing you that the Council of this Institution, at a meeting held yesterday, unanimously resolved to accept the cordial invitation of the North-East Coast Institution of Engineers and Shipbuilders to hold a Session at Newcastle-upon-Tyne and Sunderland during the summer of the present year.

As you kindly left the date of the proposed meeting an open question, so as to suit the engagements of our members, it was further unanimously resolved that Tuesday, July 26th, would be the most convenient day on which to hold the opening meeting.

I remain,
Dear Sir,
Yours faithfully,
(Signed) RAVENSWORTH,
PRESIDENT.

The VICE-PRESIDENT then called upon Mr. B. G. Nichol to open the discussion on Mr. A. Blechynden's paper on the "Reaction and Efficiency of the Screw Propeller."

Mr. B. G. NICHOL said, the paper was an exceedingly valuable contribution to the Institution, and its worth could hardly be over-rated. He regretted, owing to want of time for complete study of the paper, that he was not able to do the paper that justice which it deserved, but hoped that other members, who had been able to devote more time to its perusal, would thoroughly analyse the author's conclusions. The author's deductions were based on the results of a vast number of experiments which, there was abundant evidence in the paper to show, had been carried out with the greatest care and precision. These experiments embraced a wide range of proportion, such as varying diameter, varying pitch, and surface ratios; and in the almost perfect harmony of the results obtained during the numerous experiments and with so wide a range lay the value of the paper. It appeared to him that the author's propositions were fully and fairly established, and would enable propellers to be at once so proportioned as to obtain the maximum economy in any class of ships, and he was of opinion that rules based on these propositions would appear in all future works of engineering reference. Objection might be taken to the author's conclusions on the ground of the experiments being carried out in a tank with models, but in his (Mr. Nichol's) experience, much more accurate and reliable data could be obtained in this way, and with greater ease, than with actual vessels and propellers. At all events, the laws deduced by means of such experiments would be the same, although it might be found necessary in practice to modify some of the constants. The members of the Institution would be pleased to observe that the first six propositions agreed fairly with the deductions of those great masters of engineering science, whose memories they were so proud to honour—Professors Rankine and Froude. Proposition VII., which said, "The effect of surface is the same irrespective of the number of blades into which it is divided so long as it is similarly distributed," ought to have important consequences, first by settling the question so often raised as to the relative merits of screws with two, three, four, or more blades; and second in checking, if it does not finally abolish, the introduction of propellers of marvellous form and euphonious name, for which wonderful results are claimed and stiff royalties charged. The kernel of the whole paper appeared to him to be diagram 9 on Plate 30, described on page 193, which afforded a ready means of ascertaining the modulus C, which necessarily varies with the surface and pitch ratios. The scales given are only arranged for two examples, but the scales for all surface and pitch ratios, within the limits of practice, may readily be added, and the diagram rendered complete. The value of C for any surface and pitch ratio might then be ascertained, and when

applied in Proposition VI., afforded a ready means of fixing the proportions of the required propeller. Where varying pitches were introduced it was of the utmost importance that the true mean pitch should be ascertained, as described on page 197, for if this was not done, and the loose method of adding together the extreme pitches and dividing by two, as is frequently done, be taken as the mean pitch, the proportions arrived at would most probably be erroneous, and the proportions of the screws fixed might give anything but results securing maximum efficiency. In the face of the results of the experiments, many of the members, he thought, would require to modify their views with regard to pitch ratios. These results pointed to an increase in this respect which would involve a reduction in the diameter of screws and an increase of revolutions of the engines, in order to obtain the most economical results.

Mr. TAYLOR said, Mr. Nichol had praised the paper about as much as a paper could be praised. He was sorry to say that he differed entirely from Mr. Nichol. He considered the paper was loosely written and consequently involved. The writer used many terms without explaining their meaning. As an example, what was to be understood by the term "indicated thrust?" He knew what the late Mr. Froude meant by "indicated thrust," because Mr. Froude fully explained what he meant to convey by the term. But the writer evidently meant something quite different; probably the thrust indicated by the spring balance shown on Fig. 2. Neither does the writer explain how he conducted his tank experiments, nor how the tabulated results were arrived at, and therefore he could neither follow the writer nor place any reliance upon the experiments, because he could not follow his steps. Mr. Nichol said, practically the propositions were everything that could be desired. He should like to know what the first proposition was intended to convey. It read thus—"In any screw the turning moment is independent of the quantity of surface, or of the mode in which it is distributed." To support this proposition the writer stated "this is a conclusion arrived at by Mr. Isherwood and is clearly proved by his experiments." If he understood the term "turning moment," it meant the product of a weight into the leverage with which it acts, and independent of the number of revolutions per minute. But were they to understand that if they cut two blades off a four-bladed propeller, the mean pressure given in Table 3, say for eight knots, would remain the same with the engines running the same number of revolutions as with the four blades? But if not these mean pressures were misleading, because they did not represent the same I.H.P. for these various speeds, while Table 3 would lead one to suppose that A B C D E and F were

equally efficient, or, in other words, required the same I.H.P. to drive the ship at a given speed. But on referring to *Engineering*, of November 19th, 1875, page 407, he found Mr. Isherwood said :—

"Water being a liquid yields by virtue of its mobility to the thrust of the screw, and that the velocity or absolute slip thus imparted to the water by the thrust of the screw will be such that the product of the square of this velocity of the water and of the surface of the screw will be constant for a given speed of vessel.

"Now if S = surface of screw and V = the velocity of the water, or absolute slip of the screw, for any given speed of the vessel, then $S \times V^2$ will be a constant for that speed of vessel, and if the value of S be changed, then to maintain the constancy of the product $S \times V^2$, the value of V must be changed in the inverse ratio of the square root of the surface. For example, let S = 25 square feet, V = 2 geographical miles per hour, with any given speed of vessel, then $25 \times 2^2 = 100$ = constant. Now if S be reduced to 9 square feet to find the value of V in the new case, the speed of the vessel remaining as before, we have $\sqrt{9} : \sqrt{25} :: 2 : 3\frac{1}{3}$ miles per hour, which is the velocity of the water pressed by the screw surface of 9 square feet to give the vessel the same speed as before, because $3\frac{1}{3}^2 \times 9 = 100$ = the constant."

In the one case they had a propeller making, say sufficient revolutions to run ten knots, and in the other case it ran eleven and one-third knots in a given time. If they were to take the mean pressures given on page 186 as mean pressure in the cylinder throughout, in one case they had the engines doing very much more work than the other; and Mr. Isherwood himself in summing up the efficiencies of these propellers said:—"That at certain speeds D is $7\frac{1}{2}$ per cent. less efficient than B." That was pretty well borne out by other experiments; for instance, he believed it was the French engineers who tried experiments with the "Pelican." They took a four-bladed propeller of a certain pitch, or rather a series of propellers of the same diameter and pitch, but the surfaces varied from ·60 of the diameter to ·28, so that the surface varied considerably. The result was that the slip varied from 25 to 30 per cent. according to the surface, while the cylinder pressure required to give one turn of screw per second varied from 1·5 to 1·3. And altogether he thought there was something which required explanation in the first proposition; he could not accept it as it stood, neither could he go beyond it. The results of trials he had made bore out what he considered Mr. Isherwood meant. He experimented with a propeller upon a small steamer, and first of all tried a four-bladed propeller; with that propeller the engines ran about eighty-five revolutions per minute, and gave a certain speed. He then cut off two of the blades altogether and the revolutions ran up to ninety-five, and of course he obtained an increase of speed; after he had done that he cut about three-and-a-half inches or about one-sixth off the remaining blades right down the back, and the engines then ran 103 revolutions per minute.

The VICE-PRESIDENT asked if the diameter was kept the same ?

Mr. TAYLOR replied that the diameter and pitch were the same throughout. On account of the way the writer presented his facts, many things in the paper, he feared, would remain a sealed letter.

The VICE-PRESIDENT said he felt he had been a little remiss. He thought that in opening the meeting it would have been only due, and the proper proceeding to have taken, to have asked Mr. Blechynden if he had any further remarks to make. Now, with their permission, if they would kindly accord him that permission, late as it was in the time of the discussion, he should be very glad if Mr. Blechynden at that stage had anything to say. He did not wish Mr. Blechynden to enter into the reply, but simply if he had any explanation to give regarding the paper itself.

Mr. BLECHYNDEN regretted that there should have been any difficulty in understanding the paper, but he would endeavour to make all clear in his reply.

Mr. WEIGHTON said, that while he could sympathise with the last speaker in the difficulties he had in arriving at the meaning of some parts of the paper, he must say he could not bear him out in regard to some of his criticisms of some of the subject matter. He thought the paper a very valuable one, and in its present form, a very great incentive for all who read it carefully to think out the subject for themselves. The paper was, doubtless, somewhat academical in its nature, and (as the writer himself mentions) very elliptical, so much so that misapprehension was unavoidable. He must confess that it was only after repeated perusals of some parts of the paper that he clearly apprehended the meaning and bearing of some of the writer's deductions. The subject being one of extreme difficulty, the writer of the paper would have been more than human had he succeeded in making himself absolutely perspicuous to every reader. At the same time he must say that in his opinion the meaning of some parts was very much obscured by the condensed method of expression adopted. One thing he thought was very much wanted, viz. :—a table or tables of the complete results of the experiments, giving the bare results, and thereby enabling any one to check the writer's deductions, to compare results, or to draw his own conclusions ; one or two points might be somewhat elucidated, he would briefly notice these. With regard to the three equations given on page 185, their application was seen in the case of progressive trials of vessels. In this case the same screw was tried at different speeds of revolution which were due to different mean pressures in the engines, and the relation between the revolutions and the mean pressures was expressed

by the above equations, if we read mean pressure instead of motive weight (W). According to equation 3, the mean pressure was proportional to the square of the revolutions. In his experience he had found that the index of the revolutions instead of being uniformly the square, varied from 1·3 to 2·6. Proposition I., as it stood, was certainly a very great stumbling block. Taken in connection with the equations just mentioned, and with Tables 3 and 4, the following seeming inconsistency deserved notice:—W is independent of surface (Proposition I.), T is proportional to W (equation 1, page 185); therefore T is independent of surface. This conclusion was, of course, false, and it was evidently held as such by the writer, because in Proposition VI. he proceeds to show how T depends upon surface, but as the text and tables stood at present the matter was very hazy. The seeming inconsistency arose from the neglect of revolutions and slip. Proposition I. can only mean that, with screws exactly similar and equal in all respects except surface, a given ship may (neglecting friction and resistance of screw blades) be driven at a certain given speed without any alteration in the turning moment on the screw, but that the screws having the larger surface will make fewer revolutions and have less slip than those with the smaller surface when the ship attains the given speed. Had Tables 3 and 4 contained the revolutions and slip, this point would have been clear. Proposition II. was a truism on the principle of work, thus:—Assuming the propeller efficiency unaltered, equal thrusts meant equal powers, and power is proportional to turning moment × speed of piston; but if pitch was doubled, the speed of piston must be halved for the same speed of ship, and therefore the turning moment must be doubled to give the same power as before, therefore turning moment is proportional to the pitch. The same argument applied to Proposition V. Indeed, it seemed to him that Proposition V. might have been taken as a first principle, and might have been used to show (which it virtually does show) that all the elements of waste work due to the action of the propeller had been taken into account and had been allowed for. The experiments did not prove the proposition—the proposition proved the completeness of certain deductions made from the experiments. The application of the truth embodied in Proposition IV. was simply this: that in passing from lower to higher speeds of revolution, the propeller pitch would be made finer, and the engines smaller to indicate a certain power. Passing to Proposition VI., the expression here given was, as the writer said, virtually Professor Rankine's, with the addition of a co-efficient C to represent the effect of surface and of pitch ratio. It might not be uninstructive to put the formula given on page 190 into a more practical

form. Assuming that $\frac{V}{f}$ was included in C, and that the slip S was a constant percentage of the speed V, we had—

$$T = C_1 D^2 V^2.$$
$$T = C_1 D^2 (PR)^2.$$
$$PR \times T = C_1 D^2 (PR)^3.$$
$$I.H.P. = C D^2 (PR)^3.$$
$$C = D \sqrt{\frac{(PR)^3}{I.H.P.}}$$
$$D = C \sqrt{\frac{I.H.P.}{(PR)^3}}$$

D = Diameter of propeller in feet.
I.H.P. = Indicated horse-power.
P = Pitch of propeller in feet.
R = Revolutions per minute.
C_1 and C = co-efficients.

In so far as the above formulæ assumed a constant percentage of slip at all speeds, and that it did not include surface, it was palpably defective, as a general rule, for all circumstances; but if the value of C were taken from instances fairly corresponding with any case in point, the rule was a very valuable one in the design of screw propellers. This would be recognised as the rule given in A. E. Seaton's admirable *Manual of the Marine Engine*, where it is stated that the average value of C for ordinary vessels is 20,000, but for torpedo boats and launches it rises to 25,000. Instead of this, his (Mr. Weighton's) experience went to show that for torpedo gunboats running up to 400 revolutions per minute the value of C fell in some cases as low as 14,500, and still with fair efficiency. The paper showed how the effect of surface upon thrust might be computed by the use of different co-efficients depending for their values on the propeller-proportions, but it did not show how to apply these co-efficients to the actual design of propellers. Seeing that it was of a strongly marked analytical nature, it was perhaps scarcely legitimate to complain that the paper did not contain practical applications, still it was needless to point out how vastly such applications would have enhanced its value to an institution such as this. It was not sufficient for the designer of a screw propeller to know how to calculate the thrust of any screw; he should also know how the relation of this thrust to the power expended in producing it was affected by the dimensions and proportions of the propeller, and by the conditions under which it worked. The "propeller question" was proverbially a vexed question, and was of great diffi-

culty. It was, however, often complicated with the question—equally difficult—of ship-resistance. If a ship fell short of the expected speed it was very usually said that the propeller was unsuitable for the ship, whereas it was quite as likely that the ship was unsuitable for the propeller. He meant, of course, that it was quite as likely that the ship's resistance had been miscalculated as it was that the propeller proportions had been miscalculated. For instance, in the equation already given on page 216 the I.H.P. depended on the ship's resistance, and should the ship's resistance exceed the calculated resistance, then the revolutions (R) would not be attained, and consequentially neither would the estimated I.H.P. be attained, nor the speed. The pitch (to mention only one element) would be too coarse, and this arose, not from any mistake in the proportions of the propeller, but solely from an under-estimate of the resistance of the ship. The difficulties peculiarly inherent in the propeller question are in this way often increased and complicated by those surrounding the problem of ship-resistance. He thought the Institution was very much indebted indeed to Mr. Blechynden for bringing before it a paper involving such a great deal of labour in its preparation as this paper evidently involved, and he was sure that Mr. Blechynden would be able to clear up those points which had been found difficult of apprehension.

The VICE-PRESIDENT said, he did not think that he could add anything to the interest of the discussion; of course, one's practical experience came in as illustrative of a very great deal that had been said, and in the course of a long engineering life they picked up a great many facts which might be used, but he did not know that they would be of use just at that moment to further the discussion. Just to mention one fact—that by the reduction of the diameter of a 12½ feet propeller six inches, and decreasing the pitch and increasing the surface, they had attained, or rather increased, the speed of a vessel from 18·9 to 19·66 knots with about the same revolutions, but with a considerable reduction of horse-power—about from 7,800 down to about 7,500, showing how much lay in the first and the original design of the propeller and its adaptability to the ship's resistance. He merely mentioned this to show the importance of that great question. He would now ask Mr. Blechynden to reply to the discussion, but he would just before doing so say that he would be very much obliged to him if he could give them a rather more complete sketch of the apparatus employed. It would be interesting to the Institution to know how the turning moment was obtained, how the thrust was taken, and how they were measured, and he believed the

Institution would be very well satisfied with the result. Another thing that Mr. Taylor asked for was that the results should be tabulated, giving the figures themselves as Mr. Blechynden obtained them, so that they might see to the accuracy of his deductions; it would be interesting in every way if Mr. Blechynden could give them that information.

Mr. BLECHYNDEN said, that as there appeared to be some misapprehension about the matter, it might be as well to state clearly that he laid no claim to having carried out the experiments made at Forth Banks. He was not certain whether they were at first suggested by himself or not. They were carried out at the desire of Mr. F. C. Marshall, but they were organised by himself and conducted by Mr. W. Crawford, who brought that skill which had already won him some distinction while under Sir Wm. Thompson to bear upon them. Such accuracy, therefore, as they may possess ought to be credited to Mr. Crawford. Mr. Nichol had referred to Proposition VII., as showing that there was no difference between screws with four, three, and two blades. This must be understood as only true in reference to the screw's reaction and when the surfaces were equal and similarly distributed. Under ordinary conditions, however, a two-bladed screw with the same surface as a four-bladed screw ought to have less edge resistance than that with four blades, and ought consequently, on this account, to have a slightly higher efficiency. He very much regretted that Mr. Taylor should have had any difficulty in understanding him, but he would now endeavour to clear away Mr. Taylor's difficulties. It was quite possible there might be some slight want of clearness in Proposition I., but, apparently, this was not the stumbling block, as the illustration which Mr. Taylor had used to show what he considered the inconsistency of the proposition showed that the meaning of the proposition was grasped, but that its truth was doubted. The intention of the proposition was to show that, supposing a vessel was propelled at a given speed by a screw of given diameter and pitch, the ship's resistance remaining constant at that speed, then, assuming the screw to work without loss from fluid friction or edge resistance—an assumption which, as doubtless Mr. Taylor had carefully noted, was made in the paragraph immediately preceding the proposition in question—the turning moment would remain constant let the surface of the screw be what it might. It would be evident to all that if a screw were used to propel a given vessel at a given speed, then—since the screw had to overcome a constant resistance—the thrust depended upon the resistance of the vessel, since it must be equal to it let the dimensions or proportions of the screw be what they might. Any change in the

dimensions or proportions of the screw might affect the revolutions at which it worked, the horse-power developed, or the screw's efficiency; but so long as the ship was propelled at the same speed the thrust would not change. He would now consider the relation between the thrust and the turning moment. He would refer them to Fig. 15, Plate 34, which represented a portion of the blade of a screw moving in the line $b_1 a_1$, which was inclined to the face of the blade at the angle $b\ g\ b_1$. The question as to the law of resistance with the angle or the velocity might be left open. It might vary with any function of either. All that was necessary was to grant that the result of the impact between the plane and the water was a resistance normal to the face of the blade. This resistance might be represented by the line $k\ h$, and $k\ h$ could be resolved into two forces at right angles to each other, namely, $k\ l$ (which he would call thrust) $= t$ in the direction of the screw's axis, and $l\ h = f$ in a transverse direction. It would be evident $l\ h$ was the turning *force* for the thrust t acting at the radius of this section. The relation between these two forces was $f = t$ tan. $l\ k\ h$, so that if t were constant then f must also be constant, and since the radius at which f acted was constant then, for the elementary portion of the blade considered the turning moment was constant, and since the relation between the two forces did not involve the surface the force f, and consequently the turning moment was evidently independent of the quantity of surface. The same principle might also be applied to all other portions of the blade. The question was asked by Mr. Taylor if it was to be understood that if two blades were cut off a four-bladed propeller the mean pressures on the pistons of the engines driving the screw would remain the same *with the same number of revolutions*. Most certainly not. There was not the slightest reason for supposing such a thing implied. Table 3 gave certain portions of the mean pressures on the cylinder of an engine used to propel a certain vessel at certain speeds with certain screws. The mean pressures were factors of the powers indicated, but they did not, as Mr. Taylor seemed to suppose, *represent* the powers, nor were they ever meant to do so. They might be said to represent the turning moments if they represented anything else than themselves. What would occur were two blades removed from a four-bladed screw which was used to propel a vessel at a given speed would be an increase of revolutions until the mean pressure on the blades was doubled, and the same thrust exerted as before, when the turning moment would also have become equal to what it was before the blades were removed. The horse-power and the efficiency might thus be altered, but these had nothing to do with the question which related only to the

turning moment. He feared Mr. Taylor's difficulties arose from a confused idea of the mutual relations existing between pressure, revolutions, and the power developed in an engine. Mr. Taylor had introduced a quotation from Mr. Isherwood's paper—for what reason he could not understand, as it had no bearing whatever on the point under discussion. He regretted he could not from memory quote what Mr. Isherwood did say upon the point at issue.* Since Mr. Isherwood had been quoted, he desired it to be understood that, while he accepted him as an authority, he drew his own conclusions from Mr. Isherwood's data. Mr. Isherwood's deductions he believed to be generally sound, but in the unfortunate paragraph which Mr. Taylor had chosen for quotation Mr. Isherwood was unquestionably wrong. The reasoning led to the conclusion that the slip was proportional to the square root of the surface, a deduction seemingly upheld by a comparison of the slips of the screws A B C D E and F with the square roots of their surfaces; but as the slips compared were the *apparent* and not the *real* slips this support failed. The "Pelican" experiments had been referred to. These were, without doubt, most carefully planned and executed, and were of immense value in the early days of screw propulsion. He feared, however, that they would assist but little in designing screws to meet the varied requirements of modern practice. There was one important want in the carefully tabulated mass of data—the true slips, which were essential to the practical treatment of the subject. His friend, Mr. Weighton, had proposed a modification of the formula of Proposition VI., and had sketched it out upon the board, where it still remained. At the outset he must candidly say that he viewed this modification as going a step backward, and that while he owned it had the merit of simplicity, it had also, unfortunately, those practical objections from which it had been his endeavour to rescue it. It was an old freind, and had appeared under many forms. It reminded him of an attempt to estimate the power exerted by a locomotive from the dimensions of the cylinders and speed only, without any reference to the weight of the train it was drawing or the inclination of the rails on which it ran. Let them consider this proposed modification, which was a correct deduction assuming slip ratio, surface ratio, form of screw and

* As it may be interesting to the members to know what Mr. Isherwood does say the quotation is now given from page 525, *Engineering*, Vol. XX.:—

"*Of the Influence of Different Surfaces of Screws otherwise the same, on the Piston Pressure.*—It is evident that, with the same engine and the same pitch of screw, abstraction being made of the friction of the screw surface on the water, the net pressure on the piston of the engine must be the same at the same speed of vessel, let the surface of the screw and its slip be what it may."

pitch ratio all constant, a range of constancy, it need hardly be said, quite above the character of the average screw, but for the sake of concentrating their ideas it might be granted that all screws were similar, and that they had left only constancy of slip ratio to consider. A moment's thought would show how utterly inconsistent this was with fact. If they would take the case of two screws the same in every respect, applied to two ships of the same form, but of which one was larger than the other, and that these screws were driven at the same number of revolutions, the formula, if applied without correction, would give the same power as exerted in each case; yet it was well known that this would not be in accordance with fact, but that a much greater power would be developed on that screw which was applied to the larger vessel than upon the other, since the larger vessel having the greater resistance its screw would work with a greater slip ratio than that of the other. Thus it appeared necessary to apply a correction to different cases, and the constant, whose distinguishing characteristic was variableness, had to be modified. This was because the formula assumed what was utterly untrue. The figures given for the value of C illustrated this. They were 20,000 for ordinary vessels and 25,000 for torpedo boats and launches. It would be evident that the vessels happening to be merchantmen or torpedo boats was away from the question, which was simply one respecting the form, dimensions and speed of the vessel relatively to the dimensions and proportions of the screw used to propel it, and Mr. Weighton's experience that the value of C was lower instead of higher for torpedo boats, simply indicated that the vessels to which he referred must have had screws of different proportions from those for which the value of 25,000 had been worked out. From the formula $D = C\sqrt{\frac{I.H.P.}{(PR)^3}}$ we had $I.H.P. = \frac{D^2P^3R^3}{C^2}$. It would then be evident, by inspection, that the larger C happened to be the smaller would be the horse-power which was developed upon a screw of given diameter, and since (neglecting friction, etc.) the power and the thrust were directly proportionable to the slip, then it was evident that C must vary inversely with the slip and the thrust. The thrust was, however, equal to the resistance of the ship of which the screw was the instrument of propulsion, therefore, increase of C indicated decrease in the proportionate resistance of the ship to which the screw was applied. In fine—if two screws were applied to propel two vessels A and B at the same speed, then if that factor of the resistance which involved the dimensions and form were greater in the vessel A than in

the vessel B, the value of C would be smaller for the screw of A than for that of B.* He was perfectly aware that Mr. Weighton was fully cognisant of these facts, but as the thing had been left, he feared it might be supposed that Mr. Weighton intended it to be used without the very great corrections which were necessary, and which could only be applied by the experienced. He thanked Mr. Weighton for his suggestion as to the advisability of showing the practical application of the principles treated in the paper, but it was needless to say that it was better to thresh out as far as possible the principles first and to follow with the application. As it happened, the paper had in the treatment of the principles alone been quite long enough. It had been suggested as advisable that the whole of the data relating to the model experiments should be published just as they had been put into his hand. There would be no practical difficulty about doing so. The figures were all carefully tabulated, but he feared the financial difficulty would be considerable, and the figures themselves might be a weariness to the flesh, as they would be a mass of printing equal to, if not exceeding, the whole of the paper. So far as the data for the screws of the *c k* series were concerned, it seemed useless

* Doubtless the wetted surface cannot be taken as the true measure of a ship's resistance, but within certain limits it is so, and it may at least be used to illustrate the preceding remarks. In the following table the trial powers of certain vessels are given, and the values of C calculated by the formula $C = D\sqrt{\frac{(PR)^3}{I.H.P.}}$ and by the side of them the ratios of the wetted surfaces of the vessels to the disc areas of the screws. In order that C might be influenced as little as possible by the proportions of the screws, those have been chosen as far as possible of the same pitch ratio. The only serious variation from this is in the case of the first on the list. It will be observed that as the ratio of the wetted surface to the disc area increases, C decreases.

Vessel.	Screw.			Trial.		C.	Ratio of Wetted Surface of Vessel to Disc Area of Screw.	
	Diameter.	Pitch.	Pitch Ratio.	Revolutions.	I.H.P.			
	Feet.	Feet.						
Yacht	5·25	8·5	1·62	320	460	34,750	35 (about).	Single screw.
Gunboat ...	10·0	12·5	1·25	136·5	822	24,700	38·5	Twin screw.
Do. ...	12·0	14·5	1·21	120	1,290	24,200	42·0	Do.
"Iris" (No. 3)	16·29	19·9	1·22	97·2	3,857	22,350	43·0	Do.
"Howe" ...	15·6	19·4	1·24	107·2	5,806	19,500	82·0	Do.
Merchantman...	15·6	19·3	1·24	60	1,060	18,900	94·0	Single screw.
Do. ...	16·0	20·0	1·25	64	1,466	19,100	97·0	Do.

The high value of C for the first on the list appears to be in some measure due to the large pitch ratio. Other examples could be given to show that C varies with the pitch of the screw, the diameter and surface remaining precisely the same and the screw applied to the same vessel. It could also be shown that all else remaining the same C varies with the surface ratio.

to tabulate them, as the motive weights and revolutions were given in the various tables for a thrust of 5·6 lbs., and for any other thrust they could be determined by use of the equations on page 185. (The method of experimenting was then further explained with the assistance of sketches on the blackboard and an example of the application of Proposition VI. to the calculation of the resistance of a screw was given.) He had put off until the last replying to Mr. Taylor's complaint that he had omitted to define what he meant by "indicated thrust" as being the point of least importance. He thought all terms which might otherwise be misunderstood had been most clearly defined at the commencement of the paper, and, for the rest, if the context of the paper did not indicate the meaning, probably any ordinary dictionary would. It was true, as Mr. Taylor had stated, that Mr. Froude had defined what he meant when he used the term "indicated thrusts," this was an absolute necessity, since Mr. Froude used the term to mean what was purely conventional, and in no sense indicated at all; but he need hardly say this was not sufficient reason why the two words should never afterwards be used in their proper sense without an apology. He thanked them for their attention and the vote of thanks they had accorded him for the paper.

NOTE OF INACCURACY IN DIAGRAM, FIG. 10, PLATE 31.

As the curves B_2B_2 and DD_2 are a little inaccurate for some of the pitch ratios, the following values of their ordinates are given in order that the curves may be corrected or checked by such as desire to use them :—

Pitch Ratio.	Revolutions.	C.
0·833	169·8	·517
1·103	145·2	·383
1·250	136·9	·321
1·449	129·6	·244
1·600	126·1	·216

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886-87.

PROCEEDINGS.

EIGHTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON WEDNESDAY EVENING, APRIL 20TH, 1887.

WILLIAM BOYD, ESQ., PAST-PRESIDENT, IN THE CHAIR.

THE SECRETARY read the minutes of the last General Meeting, held in Newcastle-upon-Tyne, on April 6th, which were approved by the members present, and signed by the Past-President.

The ballot for new members having been taken, the Past-President appointed Messrs. J. T. Milton and W. G. Spence to examine the voting papers, and the following gentlemen were declared elected :—

MEMBERS.

Brown, William, 30, St. Mary's Place, Newcastle.
Darling, W. J., Lloyd's Surveyor, Leith.
Furse, Frederick. Messrs. Hawthorn, Leslie, & Co., Limited. St. Peter's.
Inglis, John, Messrs. Ramage & Ferguson, Leith.
Laidley, Reginald William, 18, Claremont Place, Newcastle.
Nance, Alfred James, 14, Stacey Road, Routh, Cardiff.
Pilcher, F. J., 3, City Buildings, Old Hall Street, Liverpool.
Ramage, John T., The Hawthorns, Leith.
Walker, Alexander, 147, Constitution Street, Leith.

GRADUATE DESIRING TO BECOME A MEMBER.

Keene, Harry Ruck, 35, Church Street, Pembroke Dock.

The PAST-PRESIDENT said his first duty that evening was to apologise for the absence of their President, who, he understood, was detained on the Continent, and unable to get home for that meeting. He was sure it would be a regret to their President that he was unable to attend. The next business was the notice of the proposed alterations to the Bye-Laws. It would be, of course, understood by the members that the alterations were not open for discussion that night, but, in accordance with the Articles of Association, they had to be presented at the meeting prior to the last business meeting of the session, and a notice given, so that they might discuss and decide upon them at their next meeting. The alterations that were proposed were not of a very vital character, but he must take that opportunity of saying that the Council had had before them one matter of very vital importance, viz., the financial position of the Institution. A sub-committee had been appointed, of which he had the honour of being appointed Chairman, and it had given very minute and careful consideration to the whole subject of the amount of subscription for members. That sub-committee subsequently reported to a meeting of the Council, held about a week ago, when the matter was also discussed at great length. It was right that the Institution should know what the position of their affairs was. As they were aware there was a credit balance of the funds at the end of the first year's working, which almost entirely disappeared at the end of the second session, and they were now at the close of the third year, and that balance would be, to a certain extent, restored; but the Council felt very strongly that the field of usefulness could be very much enlarged if the funds were in a more flourishing condition, and it was discussed whether they should not raise the subscriptions of ordinary members from 10s. 6d. to 15s., or even £1 1s. The problem was a difficult one, and on the one hand the Council felt it extremely desirable to raise the income of the Institution, but on the other hand, there were such serious objections to interfering with the original subscription of 10s. 6d. that they hesitated to do so unless they were able to show an overwhelming case to the members. Eventually, it was agreed at the Council Meeting that the matter should be allowed to remain in abeyance until the opening of next session. He merely made those explanations because he was asked to do so by the Council at their last meeting, so that the members generally should understand that the subject had not been ignored by the Council, but had been dealt with to the best of their ability. The alterations to the Bye-Laws which the Council did propose were as follows, viz., that in Articles 9 and 10, alterations should be made by which their present

Treasurer should be distinguished as Honorary Treasurer, and that he should discharge the duties appertaining thereto; and that their Secretary should discharge the duties of collecting subscriptions, etc., on such terms as might be decided upon by the Council. The other alteration was that Article 13 should be altered, so that that class of members whom they described at present as "Associates," and who were at present not eligible for office, should be eligible as members of Council. Then, Nos. 7, 11, 30, 31, 32, and 33 Bye-Laws would require slight verbal alterations to carry out the proposal which was made by the Council that their present Secretary should also act as Treasurer. The present Bye-Law No. 36 would be expunged, and it was proposed to insert the following, viz.:—"No. 36.—Copies of papers to be read during any session will be sent seven days before the date of reading to Members who shall have applied to the Secretary for them, in writing, at the commencement of the session. The discussion on a paper shall not be considered closed on the evening on which it is read, but shall be open for renewal at a subsequent meeting, prior to the reading of the paper set down for that date." In that alteration they followed the lines of the Mining Institute. That was the gist of the alterations proposed, which would be in their hands as soon as possible, and which would be voted upon at the final meeting of the Institution on the 4th May. The next business on the agenda was the nomination of officers for the ensuing year. The following was the list of nominations proposed by the Council, viz.:—President—W. T. Doxford; Vice-Presidents—B. C. Browne, J. H. Irwin, H. Macoll, H. F. Swan; Hon. Treasurer—B. G. Nichol; Councilmen—W. J. Bone, W. Kilvington, F. C. Marshall, Thos. Millar, Jas. Patterson, Jas. Readhead, L. Rusden, P. Watts. His duty now was to ask whether any gentleman present wished to add any names to those already read out.

No names were added.

The SECRETARY then read Mr. J. P. Hall's paper on "Compound *v.* Triple Expansion Engines from a Shipowner's point of view."

COMPOUND *v.* TRIPLE EXPANSION ENGINES, FROM A SHIPOWNER'S POINT OF VIEW.

By Mr. J. P. HALL.

It has occurred to the writer that a few facts setting forth the results of modern engineering in the mercantile marine may be of service to the British shipowner, showing more clearly, than is generally understood at present, the advantages obtained from vessels fitted with triple compound engines, as compared with the ordinary double compounds.

It is not intended, in this paper, to attempt to discuss the many varying features in the numerous designs of the triple compound engines, but merely later on to point out some of the proportions used in the practice of the writer. The great question to the shipowner is—What is the relative value of the new type of engines as compared with the double compound?

Before submitting the tables of performances, it might be well to look at and discuss a few of the questions that are daily being raised in reference to triple engines, viz.:—

1st.—Can triple compound engines in line be made to indicate the same power as the ordinary double compound, and to only occupy the same space in the ship?

2nd.—Can the same indicated horse-power be obtained without increasing the total weight of machinery?

3rd.—What about the wear and tear of machinery: will it be excessive as compared with the ordinary compounds?

4th.—Will the life of the boilers be as long as that of those loaded to 80 or 90 lbs. pressure per square inch?

5th.—Is any more skill required in looking after the machinery and boilers at sea?

Space Occupied.—The following table will show what has been done in the shape of occupying space in the ship:—

TABLE 1.—Weights of Machinery and Space Occupied.

Mark.	Engines.		Boilers.			Furnaces.		Tubes.			Total Heating Surface.	Working Pressure.	Revolutions.	* I.H.P. on Voyage.	Total Weight in Tons.	Lbs. per I.H.P.	Space occupied in Ship between Bulkheads.	
	Stroke.	Cylinders.	No.	Diameter.	Length over all.	No.	Diam. Outside.	No.	Diameter.	Length between Tube Plates.								
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
	Inches.	Inches.		Ft. Ins.	Ft. Ins.		Ft. Ins.		Ins.	Ft. Ins.							Ft. Ins.	
*A	36	30–58	1	16 0	10 9	4	3 6	284	3½	7 1⅝	2,323	80	68	730	157	482	36 0	Compound.
*B	39	31–60	2	12 6	10 1	4	3 7	162	3½	6 10½	2,637	80	66	800	180	504	36 0	
*C	42	33–64	2	14 0	10 7	6	3 5 7/16	438	3½	7 0	3,484½	80	64	1,000	218	488	38 0	
*D	45	36–68	2	15 0	10 7	6	3 9	434	3½	6 10 9/16	3,606	80	60	1,150	258	502	38 0	
*E	48	38–71	2	12 3	15 8	8	3 7	640	3½	5 11 7/16	4,199·17	90	58	1,400	299	478	50 0	
F	42	34–66	2	13 6	10 6	6	3 4	406	3½	7 3	3,474	80	65	1,000	220½	493	38 0	
G	36	30–58	2	11 9	10 6	4	3 2	316	3¾	7 6	2,793	80	68	735	157	479	34 9	
*H	36	18½–31–49	2	11 0	10 0	4	3 3	320	3¼	6 10	2,285	150	80	830	173	467	34 10	Triple.
*I	39	21–34–57	2	12 6	10 6	6	3 2	380	3¼	7 3	2,975	150	73	1,100	227	462	38 0	
*J	42	22–35–58	2	13 0	10 6	6	3 2	442	3¼	7 0	3,310	150	70	1,160	237	457	38 0	
*K	48	27–44–71	2	13 0	16 6	12	3 4	744	3½	6 7 3/16	5,460	150	70	2,000	402	450	58 0†	
L	39	22–35–58	2	12 9	10 8	6	3 2	418	3¼	7 6	3,324	150	70	1,100	230	468½	38 0	
M	36	20–31–52	2	11 3	9 9	4	3 1½	300	3½	7 0	2,371	150	80	840	168	448	34 9	
N	48	29–44–74	2	13 3	16 6	12	3 3	712	3½	6 7	5,211	150	67	1,900	383	452	56 0	

† This is a long design of engine—valve chests being all in line with shaft. The space at fore and aft ends of engine also more than usual.

Note.—The total weight includes water in boilers and Lloyd's spare gear, etc., when in sea-going condition.

* Maximum or highest average horse-power on voyage.

Table 1.—In columns 14 and 17 are given respectively indicated horse-power and machinery space between bulkhead in ship; in each case we have more horse-power in the triple engines for the same space.

It is quite common with engine builders to give the same indicated horse-power without asking any more space fore and aft in the ship than is allotted to the ordinary compounds, the list (Table 1) representing the practice of several engineering firms on the North-East Coast. (It has not hitherto universally been done, as in the case of K on the table, which is a very long engine room, although now almost the general practice, and in all cases may be done if required. Some people advocate a larger engine room, more than is absolutely required for the holding of the machinery. This, if properly looked after, may be as suitable for the vessel as otherwise in special cases.) What is really wanted is to have the required light and air spaces as per Board of Trade rules, so as to reduce the registered tonnage by 32 per cent. on the gross tonnage. If the tonnage question is such, and there being no extra space beyond the requirements allowed between bulkheads, we have the full carrying capacity of the vessel; and, therefore, in the main, it may not be such a very vital question, even though the engineer might venture to ask the use of another or additional frame space. However, where required, it can easily and positively be arranged, equal space fore and aft, triple and compound.

Figs. A and B, Plate 38, show a set of engines of each kind suitable to indicate 1,000 to 1,100 horse-power on voyage, and maintain a speed of from 9½ to 10 knots, loaded with about 3,300 tons dead-weight on board, the ship being in each case 285 feet by 38 feet by 27 feet depth of hold.

Weight of Machinery.—Table 1 will also show, as follows, indicated horse-power in relation to total weight, including water in boilers and ship in sea-going condition. Columns 14, 15, and 16 give respectively indicated horse-power, total weight in tons, and lbs. weight per indicated horse-power.

This will show that in the main the triple compound engines are even lighter than the others. The examples marked thus * are engines that have been carefully weighed, and the others may be fully depended on as being the actual weights. This table gives a uniformity of weights in triples fully as much as existed in the practice in the days of the double compound.

Taking the weights as given by Mr. F. C. Marshall, in the paper he read before the Institution of Mechanical Engineers in Newcastle in 1880,

we have there given 480 lbs. per indicated horse-power as representing at that time the weight of machinery fitted into merchant steamers. This has practically been adhered to in the north-east compounds. We have now with triples 450 to 460 lbs. per indicated horse-power, as shown in the table.

The explanation why the weight is less in the triple compound engines, as compared with the weight of the ordinary double compound engines in relation to power developed, may primarily be found in the fact that the weight of steam required per indicated horse-power is much smaller in the case of the high-pressure triple than that of the double compound of 80 or 90 lbs. working pressure, thus demanding smaller boilers, condensers, pumps, pipes, valves, etc.

This (Table 1) is a fair representation of what is now generally done in triple compound engines, and might be considered as being the average weight per indicated horse-power; therefore, we may reasonably conclude the weight of the machinery has been reduced something like 5 per cent. by the introduction of the triple engines as compared with the double compound engines.

Wear and Tear.—The question of wear and tear cannot be so positively answered as the two previous ones. The writer considers, from the experience we have had during the past three years, that we are now in a position to form a fair and reliable opinion. He has of late made special enquiry, and is disposed to say the cost of maintenance with engines of the higher pressure, will not exceed that of the compound or lower pressure; in fact, with a well-balanced three-crank engine it should be even less.

The cost arising from the responsibility of the builders during the ordinary guarantee period of six months for a great number of vessels has not been in any way excessive, or beyond what might have been expected in the compounds. This is borne out also by the testimony of several engineers of large experience.

Messrs. Thos. Wilson & Sons, Hull, have fourteen vessels fitted with triple engines, and have had a long and varied experience with them in all forms. The first of their triples came out and made a voyage in the year 1882; they were early advocates and amongst the first to see the advantage of the application of the triple engines. Mr. Spear, their engineer, writes as follows:—"Our experience with triple engines shows that they have not been any more costly to maintain in good working order at sea than the compound engines; in fact, one of the least costly in our fleet of sixty-five steamers is a triple three-crank engine."

One feature worthy of consideration is the successful application of metallic packing in the rods exposed to the action of high-pressure steam, also to the packing of the feed pumps with the same metal; this tends to reduce the labour, cost, and detention, and to materially lessen the cost of wear and tear.

Boilers.—In reference to the life of the high-pressure boilers, the writer would point out, under this head, the relative position we now hold to that of the time of the last rise in boiler pressures, which is marked indeed. We are at the present time in a very much better position in our various boiler shops, for producing a boiler of 150 to 180 lbs. pressure per square inch, than we were at the introduction of the 60 to 90 lbs. pressure boiler. Our boiler plant to-day is quite different, it is a question of boiler making by mechanical appliances, and our present advanced machinery is quite capable of the manufacture of the heaviest boiler material now required with certainty and success.

This, in addition to the introduction of mild steel as a material for boiler manufacture, has made a marvellous change as compared with what we had fifteen to twenty years ago, almost every feature in our boiler making now coming under the power of machinery.

The design of the boiler has also, during the past few years, had more attention given to it, and the manufacture is subjected to greater supervision than ever.

The factor of safety in all its parts is the same as with the recent practice of 90 lbs. per square inch; the same water tests being applied, viz., double the working pressure; and, in the opinion of the writer, everywhere better looked after in the general design and manufacture.

The experience of the past bears out that the boiler of to-day, with its higher pressure, is equal, if not superior, in every way, both in construction and material, to what has been previously produced; and doubtless its life, from the evidence we have, will be of longer duration than anything hitherto manufactured in marine boiler practice.

The skill required at sea in doing the work of the sea-going engineer is very much the same to-day in the triple compound engine as in the ordinary compound. There are one or two points that require special or a little more attention; the engines themselves are practically the same, but the boilers probably require some additional attention and judgment in working with higher pressures. The great question on a long voyage is to keep a sharp look out upon the water supplied to the boilers.

After leaving port we find that the contents of the boiler is practically changed in eight or ten days' steaming (say in a boiler 13 feet by 16 feet

long), this being the case, it has to be replaced by ordinary supply from the feed pumps; if sea water is supplied, the density of the water at the end of eight to ten days becomes $\frac{1}{32}$ of salt, and at the end of thirty days we find a saltness that is quite high enough for any ordinary working under high pressure.

With boilers of 150 lbs. pressure it is most essential to reduce the waste of water in the engines to the minimum, also care should be taken to see that the demand is made up by a supply of fresh water, and something that will not be injurious under the excessive pressure. This is of great importance to the working engineer, and requires to be carefully attended to.

A good many failures have occurred in high-pressure boilers by the furnaces collapsing, and this is largely due to the deposit from salt water; in this condition the furnace plates become excessively hot, and under the great pressure come down very easily.

What is required in working boilers at sea is, first of all, to get a covering for the internal surfaces; after this, to use fresh water, or water as pure as can be got, avoiding scumming and blowing as much as possible.

This covering can be successfully got by the use of sheet zinc plates, supported or suspended in the water, together with a daily supply of common soda, which will form a good enamel and covering for the tubes, furnaces, and interior parts of the boiler. The use of zinc is common and generally produces good results. The practice in Her Majesty's navy is to use zinc freely and to scum very little.

The writer has no sympathy with the practice of getting a heavy scale by salt deposits to protect the surfaces exposed to the action of the water.

A Bombay voyage can be worked successfully without either scumming or blowing. The following extract from a letter of the chief engineer of the vessel marked M (Table 2) will show what has been done, and the condition of her boilers is now highly satisfactory, with a clear white covering over the whole of the internal parts:—"Boiler filled with fresh water (Cardiff Dock water), and on arrival at Port Said, 11 days 11 hours, density $\frac{5}{8}$, but owing to bank fires and canal work reached $\frac{1}{32}$ on 14th day from Cardiff. Arrival at Bombay, 23 days 14½ hours' steaming time, density reached 2¼ bare. Total time under steam 25 days 5 hours; during this time scum and blow-off cocks remained unopened."

This the writer considers the basis of good sea working. The working of the boilers at sea is a very vital question, and of the highest

importance in the management of triple compound engines. He should certainly advocate the application of some easy and simple method of making on the voyage the required amount of fresh water to meet the demands of waste, etc., and to reduce the deposit to the minimum.

Performance of Vessels as taken from the Log Books.

The accompanying table (Table 2) will show the difference in the consumption of coal used in the various vessels therein quoted. Vessels taken are largely of the ordinary cargo type as built on the North-East Coast, and fair examples of double compound engines.

It is very difficult to get absolutely reliable data, so that valid conclusions may be drawn; the writer has therefore kept to vessels with which he is in a measure conversant, and knows something about their general performance. Those that have been supplied from other engineers are carefully selected and equally reliable, and he considers the figures may be fairly depended upon.

The performances of the vessels taken in comparison are promiscuously selected, no special effort having been made previous to the commencement of the voyage to do anything out of the ordinary every-day working; care has been taken to select voyages where the weather has been reasonably fine, and as nearly as possible uniform, but beyond this they may be taken as average voyages, and such that may be repeated at any time by the several vessels, and represent their work in the ordinary weather at sea. It may also be mentioned that the engines and ships quoted in the tables herewith represent the production of six shipbuilders and six manufacturing engineers located in different parts of the North-East and West coasts.

The table (Table 2) will largely explain itself. It may only be necessary here to point out how a few of the columns are arrived at, and their object. Columns 7, 8, and 9 are means on the voyage, the draft on leaving port and the draft on arrival at the outward port. The mean is taken to represent the draft on voyage, the displacement and dead-weight following in the same course. Column 11.—The consumption is taken at a speed of 10 knots, either increased or reduced, on the assumption that the power, or coal, varies as the cube of the speed. It is unnecessary to state that this is not absolutely correct in each case; however, the difference is so slight that we may take it as being approximately correct and suitable for our purpose, especially so when we consider that all the vessels are treated on the same basis, and the range of speed is not great.

Columns 12, 13, 14, 15, and 16 have been brought to a speed of 10 knots, with 1,000 tons weight and 1,000 knots distance steamed, as a simple method of comparison.

Comparing the totals, displacement and dead-weight performance of the vessels fitted with double compound engines (eleven in all) as against the totals of the vessels fitted with triple compound engines (nine in all), we have a saving of coal on the displacement performance equal to 24·75 per cent., and on the dead-weight performance we have a saving equal to 25·38 per cent.

To compare the performance of two vessels satisfactorily we ought to have them as nearly as possible the same size, the same displacement and dead-weight, same speed, and on the same voyage. To do this we will take a few examples from the table and compare them separately—vessels as near alike as we have them, with as little alteration to the actual voyage performance as possible—to show more conclusively the saving due to the triple cylinder engines.

Let us compare H and M. These vessels are nearly the same size, speed, etc.; also, they are on the same voyage (Liverpool to Bombay and back), managed by the same owners and under the care of the same superintendent engineer, and have a good many features in common; H is an iron vessel and M a steel vessel. It will be seen by Table 2, columns 8 and 9, that even though M is steel, she is comparatively heavier in equipped weight. This proportionately reduces the saving in the dead-weight performance.

Taking results at a speed of 10 knots, as per columns 13 and 15, we have the following:—

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
H	18·892 tons.	22·72 %	29·555 tons.	21·65 %
M	14·598 tons.		23·156 tons.	

Then again, let us compare G and L. L is a steel ship, and shows relatively better performances in dead-weight as compared with G, simply by being lighter in equipped weight in relation to dead-weight.

ERFORMANCES.

Weather.	Quality of Coal.		Pressure.	Material of Ship.	Mark.
18.	19.		31. Lbs.	32.	
ate	Tyne and Welsh ...	Ty W			
. ...	Welsh and mixed ...	W Mi	90	Iron.	A
. ...	Tyne and Welsh ...	Ty W	80	Do.	B
ven	Japan and Welsh ...	Ja W	80	Do.	C
. ...	Tyne and Welsh ...	Ne	80	Do.	D
ate	Scotch and Welsh ...	Sc W	80	Do.	E
... ...	Welsh	All	80	Do.	F
ple light and fair nds.	Do.		85	Do.	G
and fair winds, fine	Do.		85	Do.	H
ven	Do.				
. ...	Do.		85	Steel.	I
ple	Yorkshire	All	80	Iron.	J
rable	Welsh	All	100	Do.	K
. ...	Com. Staithes, Hartley	All			

COMPOUNDS.

TINUED.

Weather.	Quality of Coal.	Pressure.	Material of Ship.	Mark.
18.	19.	31. Lbs.	32.	
and fresh winds, fine	Tyne			
g head winds, fine ...	Tyne and Ferrendale	150	Steel.	L
winds generally, fine	Welsh and Belgium...			
Do.	Nixon's Navigation, Welsh, and Yorkshire.	150	Do.	M
winds generally ...	Yorkshire			
and light winds merally.	Do.			
and variable winds, od weather.	Do.			
head and beam winds	Do.			
variable winds ...	Do.	160	Do.	N*
g and light winds all rough passage.	Do.			
iven	Do.			
o.	Do.			
o.	Do.			
o.	Do.			
rate	Welsh	150	Do.	O
o.	Do.			
iven	Do.	150	Do.	P
ble	Welsh and Odessa ...	150	Do.	Q*
o.	Yorkshire	150	Do.	R
rable	Hood's Merthyr ...	150	Do.	S
o.	Com.Staithes, Hartley	150	Do.	T

TRIPLES.

ering gear.

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
G	18·579 tons.	23·6 %	29·594 tons.	27·14 %
L	14·194 tons.		21·561 tons.	

Assuming G to be a steel vessel, and compared with L, we have an additional dead-weight due to the difference in equipped weight of a vessel of this size, between steel and iron, which is approximately 192 tons; this would give the saving due to the triple engines of 23·89 per cent. only, as against 27·14 per cent. as above; difference being 3·25 per cent., due to the extra weight of ship.

Let us now take D as against O. These vessels are very similar; O is a little less in displacement, more beam, and perhaps a little more difficult to drive. D is an iron vessel and O a steel vessel, but with displacement and dead-weight relatively the same.

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
D	18·934 tons.	24·59 %	28·577 tons.	24·72 %
O	14·277 tons.		21·510 tons.	

Then take K as compared with S. These vessels are both built by the same firm, engined at the same works, managed by the same owners, in every way treated alike, and practically in the same trades. K is an iron vessel and S a steel vessel.

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
K	18·348 tons.	27·26 %	27·237 tons.	29·43 %
S	13·345 tons.		19·220 tons.	

K as compared with T, the same conditions as K and S. T is a steel vessel, a duplicate of S.

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
K	18·348 tons.	22·03 %	27·237 tons.	24·35 %
T	14·305 tons.		20·603 tons.	

Let us now compare D and Q. These vessels are practically of equal speed, and as per table respectively 9·2 and 9·26 knots per hour. Bringing them both to 9 knots per hour we have the following—D, iron vessel ; Q, steel vessel :—

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
D	15·976 tons.	19·42 %	24·112 tons.	20·22 %
Q	12·872 tons.		19·236 tons.	

Then take D and P on the basis of 9 knots we have—D, iron; P, steel—

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
D	15·976 tons.	17·43 %	24·112 tons.	18·67 %
P	13·190 tons.		19·609 tons.	

E and R at 9 knots—E, iron ; R, steel. This steel ship is very heavy in equipped weight, and proportionately heavier than the iron one.

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
E	17·451 tons.	20·80 %	26·764 tons.	19·86 %
R	13·821 tons.		21·448 tons.	

Let us now take J and R at the speed as per voyage, viz., 9 knots. These vessels are built and engined by the same firm, managed by the

same owners, and treated alike in every way. J, iron; R, steel. R, as shown above, is a very heavy steel ship.

CONSUMPTION OF COALS PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of triple.	Result.	Saving in favour of triple.
J	17·981 tons.	23·13 %	27·694 tons.	22·55 %
R	13·821 tons.		21·448 tons.	

The displacement performance is the work done by the engines, and on this basis we must draw our conclusions. If we had had steel ships fitted with compound and triple engines of the same equipped weight, size, etc., we could have compared successfully both the displacement and dead-weight performance. Certainly shipowners look at the amount carried and cost of same, this can be arrived at by a reference to Table 2, in columns 13 and 15.

Steel vessels built to Lloyd's rules, as compared with iron vessels of the same dimensions, other features and the general arrangements being the same, say vessels as quoted in Table 2, varying from 2,000 to 4,000 tons dead-weight, are approximately better carriers by 7½ per cent., due to the lighter section of material used in the construction of the hull.

Taking the displacement alone, we may fairly conclude, as shown by vessels quoted in Table 2, that there is a saving in the consumption of fuel, by the adoption of the triple compound engines, as compared with double compound engines of from 20 to 25 per cent. in favour of the triple.

The writer considers the vessels quoted, fitted with double compound engines, are a representation of the best type, good examples of their class and size, and that for our future guidance we may with confidence take 22½ per cent. as representing the saving due to the adoption of the triple form of engines.

Displacement performance.—Table 3 has been prepared to meet the objection some may raise, that of it being unfair to compare the performance of vessels, by simply increasing or decreasing their consumption on the basis of the power varying as the cube of the speed, and then taking the consumption per 1,000 tons displacement, without taking into account inequality in the size of the vessels; and that each ton of displacement in a small vessel requires more power to drive it than each ton in a large vessel at the same speed.

TABLE 3.—Displacement Performance.

Mark.	Displacement.	Speed.	Consumption per Day of 24 Hours.	Consumption per 1,000 Knots at a Speed of 10 Knots for a Standard Vessel of 5,000 Tons Displacement.	Co-efficient of Coal Performance.
	1.	2.	3.	4.	5.
A	5,585	10·07	26·56	100·66	129·67
	5,950	9·54	26·20	111 95	116·59
B	3,435	8·84	12·68	98·21	132·89
C	5,045	9·916	20·2	85·79	152·12
D	4,549	9·2	16·1	91·73	142·27
E	4,483	8·8	15·8	103·88	125·64
F	5,005	9·308	20·1	103·76	125·78
G	6,870	9·25	24·25	103·28	126·37
H	6,868	9·25	22·25	94·78	137·70
	7,288	8·81	24·8	117·53	111·05
I	6,012	10·	26·5	97·63	133·68
J	4,505	9·	17·5	107·20	121·75
K	5,960	10·	25·	92·64	140·88
	5,960	10·	27·5	101·90	128·08
Mean of Compounds				100·78	130·32
L	7,260	10·1	25·5	80·41	162·31
	7,140	10·16	25·5	79·88	163·40
M	6,670	10·05	25·	84·66	154·15
	6,642	10·5	25·5	75·93	171·87
N	7,824	11·895	40·73	74·80	174·49
	8,330	11·757	41·63	75·93	171·88
	8,347	12·208	48·62	79 10	164·98
	8,506	12·333	48·86	76·14	171·41
	7,888	12·125	48·85	84·24	154·93
	8,698	12·083	48·85	79·75	163·65
	8,369	12·521	54·25	81·66	159·81
	6,981	12·059	44·16	83·98	155·41
	8,439	11·975	49·09	83·99	155·35
	7,527	12·196	50·31	87·96	148·38
O	4,310	10·	14·	64·39	202·68
	4,400	9·534	13·75	71·97	181·32
P	4,460	8·76	11·72	78·38	166·51
Q	4,292	9·26	13·	75·51	172·83
R	3,684	9·	11·	77·05	169·37
S	5,970	9 8	18·	70·78	154·36
T	5,970	10·	20·5	75·88	172·00
Mean of Triples				78·21	167·67

In this table, column 4 shows the comparative performances by bringing the consumption to that for a speed of 10 knots, for a standard vessel of 5,000 tons displacement, on the assumption that the power, and approximately the consumption, vary in proportion to the cube of the speed, and the two-third power of the displacement.

This table will also show, in column 5, what may be called the co-efficient of coal performance. In this we compare the speed cubed, the

two-third power of the displacement, and the pounds of coal consumed per hour, in the formula— $\frac{\text{Disp.}^{\frac{2}{3}} \times \text{speed}^3}{\text{Lbs. coal per hour}} = \text{Co-efficient}$. This being simply the Admiralty displacement formula, with coal substituted for power.

Column 4 shows 100·78 for compound and 78·21 for triple, or a saving of 22·3 per cent. in favour of triple. Column 5 gives a co-efficient of 130·32 for compound and 167·67 for triple, being equivalent to a saving of 22·27 per cent. in triple compound engines over double compound.

Columns Nos. 4 and 5 in Table 3 are in principle identical methods of comparison, but in different forms; in other words the saving shown is practically the same.

Although Table 3 is undoubtedly the more correct method of comparison from an engineer's point of view, yet in comparing vessels of similar size, the saving as shown on Table 2 is nearly the same, and sufficient for our purpose.

This difference in coal consumption will undoubtedly make a large saving in the work of 12 months to the shipowners who are fortunate enough to have had their vessels fitted with triple compound engines. The writer will now endeavour to show what the saving amounts to in a single vessel over a period of 12 months.

Take a vessel to carry, say 3,000 tons dead-weight, at a speed of 9 to 9½ knots per hour, and assume the steaming at sea to be 250 days per annum (which is a fair proportion or average of the work done at sea by efficiently managed vessels), with a difference of consumption of coal, of from 16¼ to 12½ tons per 24 hours; this on 250 days, at a cost of coal of 20s. per ton, as pointed out by the President in his inaugural address, being the all round value, and which we may accept as near the correct price, will mean a saving to the owners of nearly £1,000 per annum, without taking into consideration any other advantages which the new type of engine may possess.

The difference in the cost of coal would be as above stated £1,000. This on £23,000, which is to-day a fair price for a cargo steamer of this dead-weight, would be equal to a dividend of 4·34 per cent. per annum.

To further show the difference in cost of coal for a period of 12 months, between a vessel fitted with triple, as against double compound engines, let us take D as a vessel capable of carrying 3,000 tons, and on a voyage to Bombay and back to the Tyne, at a speed of 9·2 knots as represented in Table 2, column 3, we have the following cost of coals, on a voyage to Bombay and back to the Tyne as per Table No. 4.

TABLE 4.

Voyage	Distance Steamed. Knots.	Days on Voyage approximate.	TRIPLE. Cons. per Day.	Engines.	Donkey Boiler, Galley, etc.	Received.	Rate.	Amount. £	s.	d.	COMPOUND. Cons. per Day.	Engines.	Donkey Boiler, Galley, etc.	Received.	Rate.	Amount. £	s.	d.
Shields to Malta	2,600	12	12·5	147	10	513 =157	6/6	166	14	6	16·1	190	10	513 =200	6/6	166	14	6
Received at Malta						356 119	19/–	113	1	0				313 227	19/–	215	13	0
Malta to Bombay	3,972	18	12·5	225	15	475 =240					16·1	290	15	540 =305				
Used in Bombay					20	235 20							20	235 20				
Bombay to Aden	1,637	7½	12·5	93	6	215 = 99					16·1	115	6	215 =121				
Received at Aden						116								94 40	30/–	60	0	0
Aden to Port Said	1,395	6½	12·5	79	5	= 84					16·1	102	5	134 =107				
Received at Port Said						32 43	25/–	53	15	0				27 70	25/–	87	10	0
Port Said to Malta	940	4	12·5	53	4	75 = 57					16·1	69	4	97 = 73				
Received at Malta						18 159	19/–	151	1	0				24 200	19/–	190	0	0
Malta to Tyne	2,600	12	12·5	147	10	177 =157					16·1	190	10	224 =200				
						20		484	11	6				24		719 484	17 11	6 6

Saving in favour of Triple per voyage = £ 235 6 0

Table 4, page 242, shows the cost of the coal bill in the case of the compound to represent £720, and the same vessel, assumed to be fitted with triple engines, the coal bill represents £485. In reference to the ship as fitted with compound engines this is an actual voyage, and the coal account as invoiced, the triple engine is represented as starting with the same dead-weight, calling at Malta outwards, and is in the same relative position on leaving Bombay, calling at Port Said for a small quantity of coal, and arriving at the same home port with a balance of coal on board equal to that as shown by the double compound. This shows a difference in favour of a vessel of this size fitted with triple engines of equal to £235 per voyage; this on four voyages per annum will represent a total of £940, and will show a dividend equal to about 4·09 per cent. on the value of the vessel; this is exclusive of the consideration of port dues in the case of the vessels fitted with compound engines, when calling at Aden, which means expense and detention.

Table 5, on the following page, is a voyage abstract of the vessel marked M on a voyage to Bombay and back to the United Kingdom, which represents a saving per voyage of £374, or four-and-a-half voyages per annum is a saving of £1,683; this on the value of the ship, £36,000, is equal to a dividend of 4·67 per cent. per year.

Renewing the present engines.—The President in his opening address pointed out the great amount of work to be done in the shape of renewing engines to the triple type, and removing the old double compounds, or tripling same. Doubtless this will be done very extensively at an early date. Perhaps the wisest plan, if money was forthcoming, would be to take the engines and boilers out totally, and supply new, exclusive of the shafting and ship-side valves, etc., which might remain in.

Next is tripling the present good compound engines, which may be done with very great success. Many ways have been suggested by which this may be accomplished, and has actually been done. The writer considers the most efficient way is to add an engine to the forward part of the present engines, as per Fig. C, Plate 39. He thought they did not get the full advantage out of the triple engines by the fitting of an additional high-pressure cylinder over either of the present ones. The fitting of an additional cylinder forward, as will be seen from the plan, can be done without removing or alteration to the existing engines in any way beyond replacing the high-pressure cylinder. The engine space is lengthened a little and the boiler space reduced; the boilers being made large enough in diameter, with a length a little shorter than the usual practice in new work. This the writer considers of no special importance, and would

TABLE 5.

Voyage.	Distance Steamed. Knots.	Days on Voyage approximate.	TRIPLE. Cons. per Day.	Engines.	Donkey Boiler, Galley, etc.	Received.	Rate.	Amount. £	s.	d.	COMPOUND. Cons. per Day.	Engines.	Donkey Boiler, Galley, etc.	Received.	Rate.	Amount. £	s.	d.
Cardiff to Malta	2,160	9	25·	223	9	1,212 232	9/–	545	8	0	32·2	288	9	1,212 =297	9/–	545	8	0
Received at Malta	...	...	...	...	...	980 ...	...	...	...	...	..	...	...	915 184	19/–	174	16	0
Malta to Bombay	3,972	16	25	412	16	=428					32·2	531	16	1,099 =547				
Used in Bombay	...	...	...	...	20	552 20							20	552 20				
Bombay to Port Said	3,032	12	25·	314	12	532 =326					32·2	405	12	532 =417				
Received at Port Said	...	...	...	...	...	206 ...	...	...	..	...	...	...	...	115 39	25/–	48	15	0
Port Said to Malta	940	4	25·	98	4	=102					32·2	126	4	154 =130				
Received at Malta	...	...	...	...	...	104 187	19/–	177	13	0				24 346	19/–	328	14	0
Malta to Hull	2,518	10	25·	261	10	291 =271					32·2	336	10	370 =346				
						20		723	1	0				24		1,097 723	13 1	0 0
Saving in favour of Triple per voyage = £																374	12	0

certainly recommend the plan (Fig. C) as the most efficient and successful way of arriving at results, similar to what we get out of the best class of triple engines when new.

Triple compound engines will doubtless take a stand for some time without deviation from the present lines. Quadruple expansion, or four cylinder engines can be worked successfully and economically at a pressure of 150 to 180 lbs. pressure per square inch. This of course is within the boiler capacity of to-day, but the writer considers that the triple compound three-crank engine will be as efficient and as economical as the quadruple engine, with its source of saving resulting from four cylinders, and less range of temperature in the various cylinders, but on two cranks in tandem. The work to the engineer consequent upon the quadruple tandem design would be greater, less accessible, and not likely, in the writer's opinion, to supersede the three-crank triple. If, however, the quadruple compound comes into use the writer anticipates it will come in the form of an additional cylinder fitted over the first cylinder on the present three cylinders in line, triple compound engines, retaining all the advantages of the uniform balanced crank, set at 120 degrees.

Engine description.—The following is a brief description of the type of engine adopted by the writer as per Figs. D and E, Plate 40, and a few of the leading proportions. The working pressure being 150 lbs. per square inch.

The cylinders are arranged in line with each other over the centre line of crank shaft, the high-pressure being forward, the intermediate next, and the low-pressure aft ; the steam thus passing from the boiler to the high-pressure cylinder, and then to each of the others in as direct a manner as possible.

Each cylinder transmits its power to a separate crank, the cranks being placed at angles of 120 degrees apart, with the "low-pressure leading" or sequence of low, intermediate, and high. The cylinder capacities of the high, intermediate, and low-pressure cylinders respectively are represented by 1, 2·65, and 7. With these proportions and "suitable cut-off" equality of power in the three cylinders may usually be attained ; care, of course, being taken to give ample size of steam pipes and port area so as to have a moderate velocity of steam.

With the sequence of cranks previously mentioned the range of temperature in the cylinders is considerably less than with the "high-pressure leading," thus minimising the loss due to the condensation by the action of the cylinder walls. Diagrams Nos. 1 and 2, Plates 41 and 42, will show this difference. No. 1 being cards taken from an engine with the

high-pressure leading in the order—high-pressure, intermediate-pressure, and low-pressure, and No. 2 with the low-pressure leading in the order—low-pressure, intermediate-pressure, and high-pressure.

The equality in the initial stress in the various cylinders, and uniformity of power on these dimensions when in regular work tends to give a twisting moment on the crank shaft very uniform, and certainly adds to more regularity of motion throughout the engine.

The valves adopted are of the piston type for the high-pressure, and ordinary slide-valves for the other two cylinders; the high-pressure and intermediate valves are placed on centre line of engines, and the low-pressure in the front, thus making the centres of the engines equal to each other. They are worked by the ordinary double-eccentric and link motion.

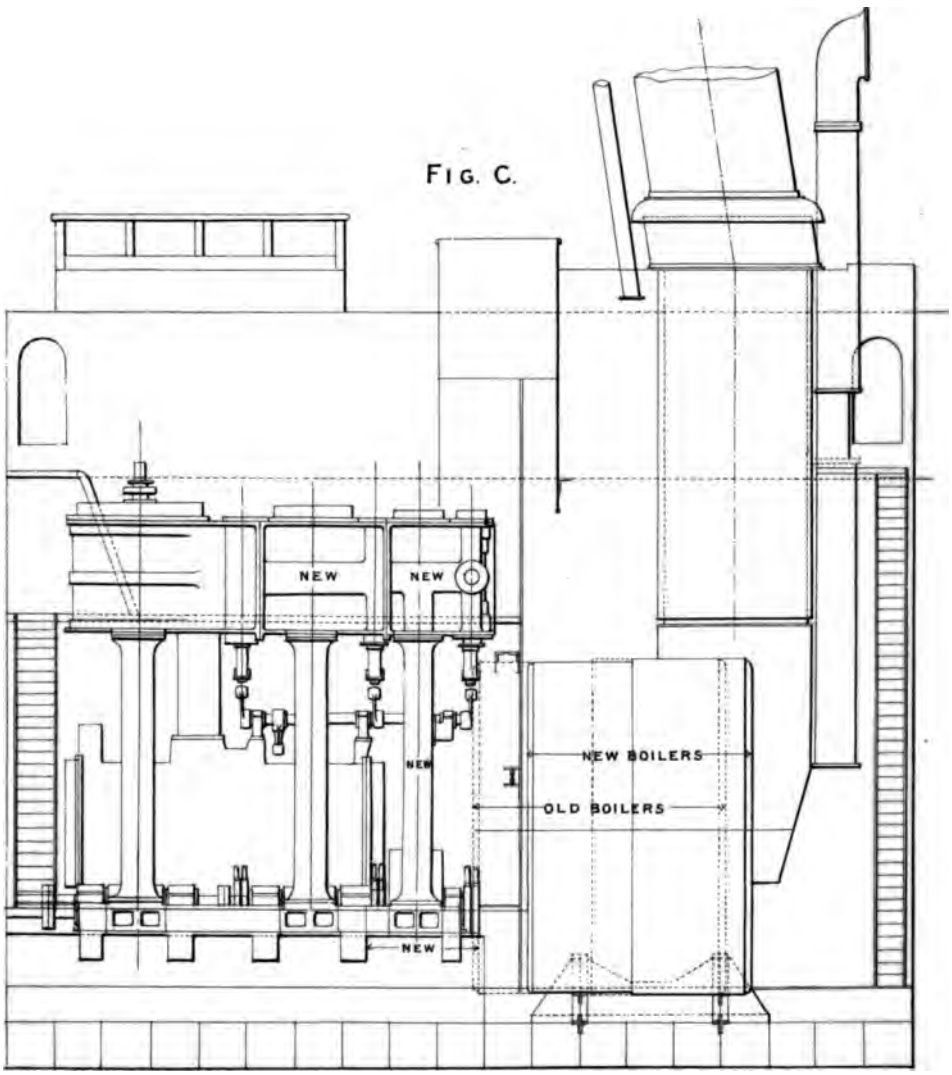
The condenser, air and circulating pumps, etc., follow the proportions of the low-pressure cylinder on the lines of the practice in the double compound; or these may vary in the ratio of the steam used; say, with the double compound, we use 18½ lbs. of steam per indicated horse-power per hour, which has been fully established, and in the triples we have 15 to 15½ lbs.; the terminal pressure being the same in each case.

For boilers, the writer considers an allowance of heating surface of 3·2 to 3·4 square feet per indicated horse-power when in regular work on the voyage, a fair and even ample proportion; and that the grate surface is quite in order when so designed as to allow for 10 to 11 horse-power being developed per square foot on the same conditions.

The PAST-PRESIDENT said, it gave him particular pleasure to be able (through the unfortunate absence of Mr. Doxford) to take the chair that evening, as he was naturally very much interested, more perhaps, in the author of the paper than in the paper itself, as Mr. Hall was connected with him for very many years at the Wallsend Slipway Co. There were just one or two points in the paper to which he should like to be allowed to speak upon by way of opening the discussion. In the first place, by reference to Table 1, he thought Mr. Hall was a little too sanguine in his statement which he made further on that "we may reasonably conclude the weight of the machinery has been reduced something like five

To illustrate Mr. Hall's paper "On Triple Expansion versus Compound Engines."

FIG. C.



To illustrate Mr. Hall's paper "On Triple Expansion versus Compound Engines."

FIG. D.

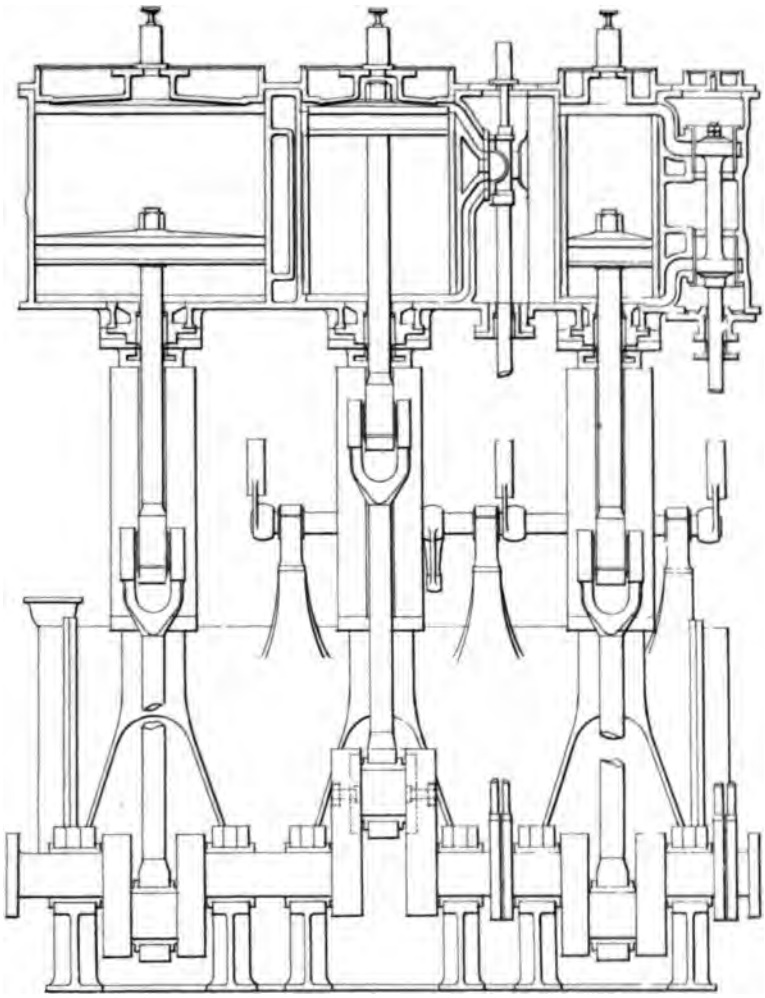
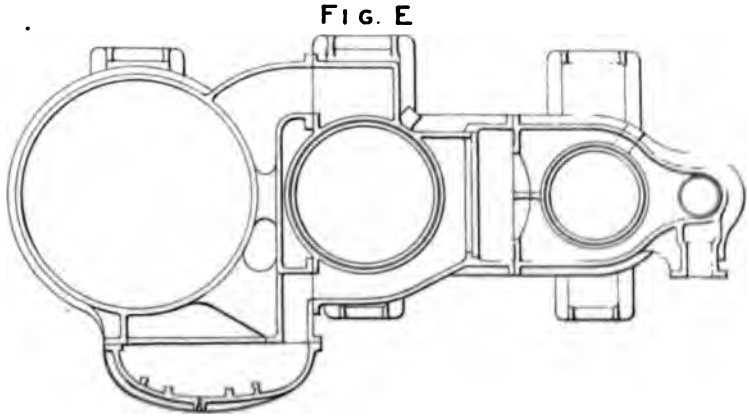
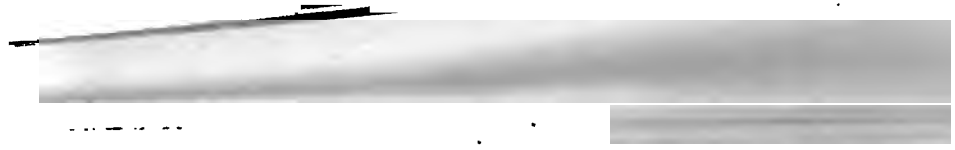


FIG. E.





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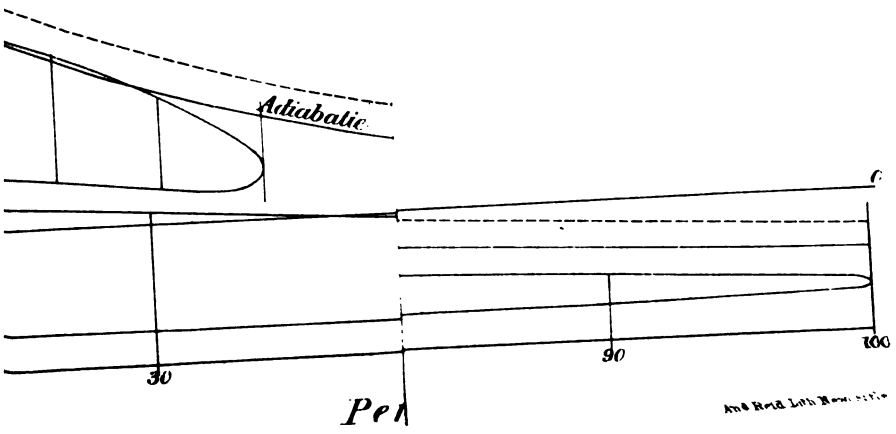

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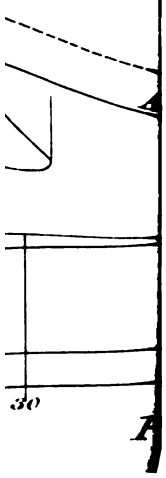
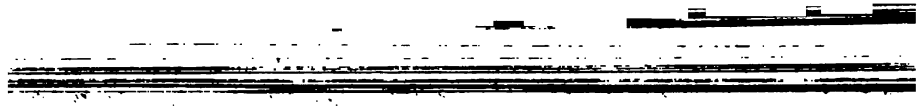




per cent." If they would refer to the vessels represented by the letters H, I, and K on Table 1, he thought that Mr. Hall had exaggerated the indicated horse-power which might be obtained from those vessels in ordinary conditions at sea. The average of those vessels showed a heating surface of 2·7 per indicated horse-power, whereas in the last paragraph of the paper Mr. Hall had, as he thought, very properly pointed out that an allowance of heating surface of 3·2 to 3·4 square feet was something like the mark. The consequence was that whereas the average of those seven vessels, which were contained in the latter part of Table 2, gave the indicated horse-power of 1,240, and a weight per indicated horse-power of 461 lbs., he thought that the indicated horse-power should be reduced to 1,150, and consequently give a weight of 495 lbs. per indicated horse-power. If they took the first part of the column, they would find that the weight per indicated horse-power came to 501 lbs. The consequence was that the two were practically identical. He thought Mr. Hall might have contented himself with saying that the same power could be obtained (he was not speaking of specially designed engines, but ordinary engines of commerce) in ordinary conditions and ordinary designs with equal weight under the one system as the other. His view was borne out by reference to page 231, where he found that if they took an ordinary pair of compound engines indicating 1,000 horse-power, they would have two boilers 13 feet 6 inches by about 10 feet 6 inches long; those boilers would weigh about 50 tons, and the water contained in them about 35 tons, or say a total of 85 tons; and if they took the same power for triple expansion, they would have a pair of boilers 12 feet 6 inches diameter by 10 feet 6 inches long, which would weigh rather more, or about 51 tons, the water in the boilers 34 tons, or say a total weight of 85 tons, ready for sea, and thus they arrived at identically the same weight, as far as the weight of the boilers was concerned for each type, so that the saving in the total weight of the propelling machinery, if any, must be got in the engines. As it is of course obviously impossible that a third cylinder, with its corresponding bed-plate, piece of crank shaft, etc., can be added to the front of the compound engines without increasing the total weight, the solution of this apparent paradox is found in the fact that in the three-crank engine an increased piston speed is possible, and thus that the same indicated horse-power can be got out of cylinders smaller in diameter and of shorter stroke; and the added weight of the third cylinder, etc., etc., is thus absorbed into at least the same weight as was necessary for any given indicated horse-power in the compound type. He wished it to be clearly understood that he referred

solely to engines such as were ordinarily made and designed for the merchant service, and such as they were unfortunately compelled to sell at a very low price. There was another very interesting point with regard to the necessity for providing a supply of fresh water during the voyage. In two or three vessels, into which he had had to fit the engines, a tank was fitted in the engine and boiler space, to contain 50 tons of fresh water; and a very ingenious contrivance was suggested by an engineer who had charge of a vessel, by which a set of pipes were led from the waterway, so that in the wet weather the water ran down into the tank, and as that vessel was trading in a tropical climate, and where a good deal of rain fell, he believed that the result had been very successful. He should be very glad if some member would speak upon the sequence of cranks as given on page 245, which was a very important matter.

Mr. B. G. NICHOL said he was very pleased to have heard the excellent paper by Mr. Hall read, and to have the opportunity of making a few remarks upon it. The paper was ostensibly written for the benefit of shipowners; but he felt sure that both shipbuilders and engineers would derive considerable advantage from the mass of valuable information the author had placed before them. He thought it a good plan to have the leading points of the paper ranged under separate heads, as tending to further the progress of the discussion. Referring to Table 1, page 230, he said the recorded results appeared to be trial trip performances, while those recorded in Table 2 were actual results obtained during voyages. The maximum results, or those obtained on trial trips, probably afforded the most useful data for the engineer and shipbuilder; but he thought the shipowner would prefer the comparison between the double and triple cylinder compounds to be made on the voyage performances, and in his remarks on their comparative merits he would confine himself to Table 2. A glance at this table showed conclusively the author's first contention to be sustained, viz, that triple compound engines in line could be made to indicate the same power as the ordinary double compound, and to only occupy the same space in the ship, and it was therefore unnecessary to dwell upon that particular clause. Table 1 showed triple compounds to be lighter, per indicated horse-power, than the ordinary double compounds—to which the President had just referred—which was certainly not borne out by Table 2. For example, the double compounds marked C, D, and E, in Table 1, corresponded with those marked D, C, and I, in Table 2; and the triple cylinder engines marked I, J, and K, in Table 1, agreed with those marked Q, O, and L, M, in Table 2; and the indicated power developed on the various voyages showed the average weight

of the three double cylinder engines to be 560 lbs., and of the three triple cylinder engines to be 565½ lbs. per horse-power, making the triples slightly heavier; but the difference was so small that the second question might be answered in the affirmative, viz., that the same indicated power can be obtained without increasing the total weight of machinery. The reason assigned by the author why triple compounds were as light, if not lighter, than double compounds was, primarily, the greatly reduced quantity of steam required per indicated horse-power by the triples. He thought they might ascertain, at least approximately, the average quantities used by the two types, and how it affected the weight. Grouping the three ordinary compounds, the average heating surface per indicated horse-power was about 3·64, and the average for the three triples about 3·424 square feet; the average ratio of heating surface to coal burnt per hour, 2 square feet for the two, and 2·424 square feet for the three cylinder engines. Assuming the temperature of the feed water, in all cases, to be 100 degs., and that of evaporation for the two cylinder engines at 324 degs., corresponding to 80 lbs. pressure, and for the three cylinder engines 366 degs., corresponding to 150 lbs. per square inch, Rankine's approximate rule gave an evaporation of 8·599 lbs. of water per pound of coal for the ordinary compounds and 8·8255 lbs. for the triples. These figures, multiplied by the total pounds of coal consumed per hour by each type, and divided by the corresponding indicated horse-powers, gave for the double cylinder engines 16·2574 lbs. of steam per indicated horse-power per hour, and for the triple engines 12·578 lbs., or 23 per cent. saving in favour of the triple engines. These quantities appeared to him to be too small; but as both types were treated in exactly the same way, the amount of saving would not be altered even if they got the precise quantities used in each case. The saving in the amount of steam and consequently of coal, as worked out, agreed almost exactly with that shown by the coal cost per thousand tons carried a thousand miles, the displacement performance showing an average saving in favour of the triples of 22·33 and dead-weight performance 23·17 per cent. The economy secured by the adoption of triple compound engines might be taken advantage of in various ways. The heating surface, and consequently the size and weight of boiler, may be reduced until the coal expenditure per horse-power is the same as in the ordinary compound type, or the same proportion of heating surface may be retained and a saving of about 25 per cent. of fuel effected, or, again, a compromise may be made between these limits, and this plan seemed to find most favour. In any case the cooling surface could be reduced about 20 per cent., say from

2 to 1·6 square feet per horse-power, giving a smaller condenser. The circulating pump in the same proportion, say from 10 cubic feet of water per horse-power to 8 cubic feet, air and feed pumps in the same ratio, with a corresponding reduction in the dimensions of all pipes and connections. He thought the cost of maintenance should not be greater in the triple than in the ordinary compound engine, in consequence of the more perfect balancing of parts and greater uniformity of the strains to which the heaviest and most costly parts of the machinery were subjected, by which its durability would be considerably increased and frequency of adjustment lessened. He thought the evidence of Mr. Spear on this point was conclusive, and remembered that Mr. Taylor, who had had large experience of both types, stated emphatically during the discussion of his (Mr. Taylor's) paper before the Institution that the cost of maintenance was no greater in the triple than in the two cylinder compound engines. So far as the life of the boiler was concerned he could not see that the increase of pressure could affect that in any way, the factor of safety being the same for 150 as for 80 lbs. per square inch, and that the great racking strains feared by some engineers could hardly be produced by the comparatively small difference of 42 degs. of temperature of the steam at these two pressures, and the amount of work performed by the heating surface in transmitting heat from the furnace gases on the one side to the steam on the other being no greater in one case than in the other. He did not think that more care was required with boilers at 150 lbs. pressure than with those worked at 80 lbs. per square inch. The engineer who kept the latter in good order would just as easily keep the former in the same condition. He quite agreed with the author that it was desirable to have a very thin white layer throughout the interior of the boiler and that its thickness should, by supplying fresh water, not be allowed to increase. He might mention the case of a set of new boilers in which the engineer, who was a very capable man, had found it impossible from some cause or other to get a white coating inside, and whenever he emptied his boilers to clean them the water was quite red. A careful examination showed that oxidation had been going on at a rapid rate in the vicinity of the water-line. It then occurred to him (Mr. Nichol) that, in consequence of air being heavier than steam of the same pressure and temperature, an air cushion might exist between the steam and water. Two small cocks were fitted, one in each boiler back, about the water-line, in order to get rid of the air after steam was up, and on the completion of the next voyage the boilers appeared as though they had been thinly whitewashed inside. In conclusion, he thought that shipowners

should be greatly indebted to the author for the very clear and lucid way in which he had shown that a dividend of from 4 to 4§ per cent. per annum could be realised by substituting triple cylinder compound engines for those of the ordinary double cylinder type.

Mr. F. C. MARSHALL said he did not want to occupy the time of the meeting further than to first express his indebtedness to Mr. Hall for the very valuable paper. It was of the greatest interest to every one of them to get hold of facts; they were the basis of all their action, and Mr. Hall had afforded them a series of very valuable and useful data, to say nothing of facts for future reference. Returning to a favourite subject of his, which the writer had treated very fully, and as the President himself had observed, the weight of the machinery was very fairly and accurately stated in the paper. He quite agreed with the President that the weight of the triple expansion engine need not exceed that of the ordinary compound, and in the paper they had proof that it worked out nearly the same, and might be taken as such constantly. He did think they ought to have made more progress in that direction; they had stronger and more reliable material now, yet since the time he had the honour of reading the paper which had been alluded to that evening, the weight of the machinery for merchant ships stood very much the same as it did when they were using 75 lbs. pressure. In the paper referred to he called attention to the fact that in certain classes of machinery those weights were enormously reduced, and he was glad to say that there was a tendency to a further reduction. He would just mention one fact bearing upon the "Compound *v.* Triple Expansion Engine from a Shipowner's point of view." He had recently to deal with tenders for engines and the carrying out of others, in which the weight would be ordinarily about 475 lbs., or from that to 500 lbs., per indicated horse-power; and was reduced to 390 lbs.; a very considerable reduction and an immense saving on the total weight of the machinery carried. They must not, however, shut their eyes to the fact that they could still further materially reduce the weight. There was no reason why it should not be reduced very nearly one-half. The weight of machinery carried on board a ship might be reduced from 500 to 253, and he might say that to-day they were prepared to make engines to work under ordinary commercial conditions (and he was sure his colleagues could do the same) at 250 lbs. per indicated horse-power. If they would refer to the total weight, say of a pair of 1,000 horse-power engines, given in the paper at 218 tons, and could reduce that by 100 tons, that would be surely a saving to the shipowner, and one of the objects of that Institution should be to take

advantage of such facts as they had in Mr. Hall's paper, making them the basis of action in this, as well as the other directions indicated. He quite agreed with Mr. Hall and the President as to the result of the saving that might be effected in fuel. He also agreed with the writer that triple expansion engines ought to be very much less costly. He was satisfied that the very expensive item of repairs would be very much less frequent in the future than it had been in the past. With regard to the construction of the boilers, Mr. Hall might have called attention to the corrugated furnaces, and the great results arising from their use. He submitted that the question of the factor of safety was an important point. They were still working on the factors of safety adopted for iron plates, and that factor of safety might with good reason be reduced. The enormously heavy plates, ranging from 1 inch to $1\frac{3}{8}$ inches in thickness, which they found difficult to get closed, might very easily be reduced by something like one-fifth. For many years in his experience they were in the habit of using iron plates, not one of which ever saw a testing machine, whereas at that moment every plate that went into a boiler was severely and rigidly tested. That one fact alone was a strong argument in favour of a reduction of the factor of safety. In his own practice, when free to do so, he was reducing the Board of Trade factor of safety 20 per cent., and they had the satisfaction of knowing that the Admiralty were also approaching that point. He had nothing further to add than to express his own thanks, and he was sure the meeting would express its thanks also, to the writer of the paper.

Mr. BLECHYNDEN said, he had very little to say except to call attention to one point which, in his comprehensive treatment of the question of the comparative weights of triple and double compound engines, the Vice-President did not mention, and that was a very important one. If Table 1 was examined, and the revolutions of the double compared with those of the triple engines, it would be found that there was a considerable increase in the case of the triples. The exact increase was something like 72·5 against 65, or equal to 11·5 per cent. Now, all other things being equal, the weight of the engine *per se* in relation to the power developed was in the inverse ratio of the number of revolutions at which it ran. In Mr. Marshall's paper, which had been referred to by Mr. Hall, the weight given for ordinary compound engines was 480 lbs. per indicated horse-power, and he believed this weight was for the indicated horse-power developed on the voyage. In his experience, that weight was very low, and not a common result, though he had examined a couple of cases that day and

found it actually a fact that those engines developed so high a power in relation to the weight—this power being about 90 per cent. of what had been developed on the trial trip. He might say, however, that they did not continue to run at this power more than one voyage, but afterwards at such a power as gave 552 lbs. per indicated horse-power, and this weight he believed to be very nearly the general practice. He did not know whether the powers in Table 1 were the trial trip powers, or the powers indicated on the voyage. They looked like the former, but whether the latter or former he assumed that they were the same for both kinds of engines, and assuming the weights of engine and shafting as about 37 per cent. of the total, the 11½ per cent. increase in the revolutions would be equivalent to about 37 by ·115, equal 4·25 per cent. of the total weights, thus accounting for nearly the whole of the difference which Mr. Hall had found. He took Mr. Hall's figures without criticism, as he felt certain that every care had been taken to ensure their accuracy. Increased revolutions was a very important means of reducing the weight of engines—a means which might yet, in certain cases, be taken further advantage of, though, of course, this means of reduction could not be carried out efficiently to more than a very limited extent. He presumed that when the machinery for the ordinary merchantman was spoken of as being constructed on a weight of 250 lbs. per indicated horse-power, these engines were to be fitted into some 18 knot, or other high speed ship, and were to work at a speed of revolutions which, while not impossible, was inefficient and unprofitable in a 9 or 10 knot cargo boat which were the real *ordinary* merchantmen. It appeared to him that if another cylinder were fitted so as to quadruple the three-crank triple, the proper place of application was not as the writer suggested over the high pressure, but over one of the other cylinders, so that the receiver effect might be obtained which was well known to have been so advantageous in the working of compound engines of all types.

Mr. CRAWFORD said, only those who had endeavoured to get reliable data from voyage performances of steamships could appreciate the value of Mr. Hall's paper, and, while he was fully aware of the difficulties attending the compilation of the data laid before them, he was of opinion (considering the importance of the deductions) that it should be rigorously criticised. He took it that the reliability of the deductions depended on the truth of the equation $\frac{D_3^2 \times S^3}{H.P.} = C$ where C was a co-efficient approximately constant for similar ships, the equation indirectly

involving the admission that the weather conditions were constant; now this equation being only true within very narrow limits, it was, therefore, both requisite and necessary that the comparisons should be made under approximately similar conditions. In looking at H and M, Table 2, he thought that the comparison was unfair to the compound, because while the triple engine with cylinder $\frac{27'' - 44'' - 71''}{48''}$ was indicating 1,550 horse-power on presumably sixty revolutions and working probably at its maximum efficiency, the compound with cylinders $\frac{40'' - 76''}{54''}$ was only indicating 1,100 horse-power or presumably under fifty revolutions and working probably at its maximum inefficiency, again in comparing M_1 and M_2 it would be seen that the equation used was not a fair basis of comparison, or that the information was unreliable, for with the same ship under similar weather conditions, M_2 while carrying only twenty-eight tons less and indicating only twenty horse-power more yet steamed 0·45 knots faster than M_1. If M^1 was a correct performance and we transposed the equation to get the speed of M_2 we would get $\left(\frac{232 \times 1570}{(6642)^{\frac{2}{3}}}\right)^{\frac{1}{3}}$ = 10·105 or only one-eighteenth of a knot faster. Further, compare H_1 with M_1 and H_2 with M_2 and we get widely different results both from their means and from themselves. Thus—

CONSUMPTION OF COAL PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of Triple.	Result.	Saving in favour of Triple.
H_1	17·053	9·85	22·167	10·3
M_1	15·382		24·37	
H_2	20·732	33·4	31·943	31·3
M_2	13·815		21·942	

Similar reasoning will apply to most of the other cases save S, K, and T, but here a clerical error appears to have passed unobserved, for it will be seen that the mean of two voyages of K is compared separately with single voyages of S and T; this is obviously an oversight, because it is equivalent to comparing one ship burning all Welsh coal with another burning half Welsh and half Hartley, the proper way to compare them and one that shows a closer and more valuable agreement being K_1 with S, and K_2 with T, thus we get—

CONSUMPTION OF COAL PER 1,000 TONS CARRIED PER 1,000 KNOTS.

	DISPLACEMENT PERFORMANCE.		DEAD-WEIGHT PERFORMANCE.	
	Result.	Saving in favour of Triple.	Result.	Saving in favour of Triple.
K_1	17·474	23·5	25·94	26
S	13·345		19·220	
K_2	19·222	25·6	28·534	27·8
T	14·305		20·603	

Instead of the figures given. It is interesting to note in these three last ships that in the compound type there is 9·1 per cent. less Welsh coal burned per indicated horse-power than Hartley and in the triples 7·1. He thought it would add much to the value of the paper if Mr. Hall would give the wetted surface (or failing that the immersed amidship girth) and the revolutions in each case.

Mr. W. G. SPENCE said, the two principal points of comparison brought forward in the paper before them were the relative weights and consumptions per indicated horse-power in double and triple compound engines, Table 1 being a weight table and Table 2 a consumption table. Dealing first with the consumption table, it was not a correct basis of comparison to consider engines and boilers all away together, and then credit the resulting efficiency to the engines simply. It seemed to him a great pity that in Table 2 the heating and grate surfaces for each example had not been included, as without these the boiler efficiency could not be separated from that of the engine so as to arrive at a fair result. However, in the weight table, they had the heating surfaces given for a series of double and triple compound engines. On looking over these (Table 1), one or two examples contained in it seemed to be the same or similar engines to some of those in Table 2; thus, C and D in the list of double compounds in Table 1 seemed to nearly correspond to D, E, and C in the double compounds in Table 2; and in the triples, J and K in Table 1 seemed to be similar to O and L in Table 2. Assuming that these examples were similar, and taking the relative consumptions per indicated horse-power for double and triple compounds as being the mean of all the results given in column 6 of Table 2, we have the relative heating surface per lb. of coal for these examples, as—

Double Compounds.	Triple Compounds.
$\frac{3484}{1{\cdot}955 \times 795} = 2{\cdot}24$ $\frac{3606}{1{\cdot}955 \times 1050} = 1{\cdot}757$ } Mean 1·998	$\frac{3310}{1{\cdot}512 \times 995} = 2{\cdot}2$ $\frac{5640}{1{\cdot}512 \times 1540} = 2{\cdot}42$ } Mean 2·3
Diff. = 15 per cent.	

Or again, assuming that the indicated horse-powers for the double and triple engines in Table 1 have been obtained under the same relative conditions, we have the mean ratio of H.S. to I.H.P. as 3·258 for the doubles and 2·81 for the triples, and using these and the mean consumptions per indicated horse-power as before, we have the heating surface per lb. of coal as—

Double Compounds.	Triple Compounds.
$\frac{3{\cdot}258}{1{\cdot}955} = 1{\cdot}66$	$\frac{2{\cdot}81}{1{\cdot}512} = 1{\cdot}86$
Diff. = 12 per cent.	

Thus it would appear as if the ratio of heating surface to coal consumed was some 12 per cent. greater in the triples than in the doubles; but the triples would labour under the disadvantage of the increased temperature of the water in their boilers, and consequently less rapid rate of transmission of heat from the fire. From the above it seemed to him that the greater efficiency shown in these tables was practically due to the engines alone, but in the absence of the actual heating surface for each individual example the above figures were at the best only an assumption. It would also have added greatly to the clearness and value of Table 2 had a note been appended stating what means were adopted for estimating the mean indicated horse-power over the whole voyage, whether it had been got from a series of indicator cards, taken at stated intervals, and the mean pressure of each of these cards multiplied by the mean revolutions over the whole of its interval as got from a mechanical counter, or whether the cards were taken at stated times, the engines being hand counted at each time of taking. In the latter case, engines having boilers that were stiff to steam might gain an undue advantage, as the revolutions would probably be reduced during and after cleaning a fire. Also as to how the coal consumed had been measured—whether

the quantities given had been got from the owners' bills of amounts paid for and remaining coal measured, or whether the bunkers had been measured before and after the voyage, and whether these particulars had been occasionally checked by actual weighing or measuring on to the stokehold plates. In Table 2 the author had included a column giving the D $\frac{2}{3}$ constants for each speed; it would also increase the value of the table if the midship sections could be added, as the examples could then be compared on the basis of their equivalent blocks, the midship section being the only particular necessary for that purpose which had not been given. He thought it was very desirable that if possible these particulars should be added, as he believed Mr. Hall had put himself to very great pains indeed to have the data as accurately obtained as possible. In the comparison he thought the double compounds had suffered somewhat severely owing to most of the examples working at so low a pressure as 80 lbs. In Mr. Marshall's paper of 1881 the mean boiler pressure in the double compounds in his table was then 77·4 lbs., and recent practice was from 90 to 100 lbs. Referring to Table 1, he (Mr. Spence) had endeavoured to compute the gain in weight in the engine department of the triples through the increase of their piston speed over that of the doubles, both engines being reduced to a common stroke on the hypothesis that in similar engines the piston speed varied directly as the cube root of the stroke. The mean piston speed for the doubles worked out to 442·33 feet per minute for a mean stroke of 42 inches, and in the triples to 492 feet for a mean stroke of 40·8 inches, and assuming both cases to be 42 inches stroke, the relative piston speeds would be $\frac{442{\cdot}33}{\sqrt[3]{\left(\frac{42}{40{\cdot}8}\right)} \times 492} = \frac{442{\cdot}33}{498}$, or an increase of some 12½ per cent. over that of the doubles. In Mr. Marshall's paper of 1881 the mean piston speed of the double compound engines given there was 467 feet per minute for a mean piston stroke of 47·7 inches, which reduced to 42 inches stroke would approximately be $\sqrt[3]{\frac{42}{47{\cdot}7}} \times 467 = 446$, or nearly what Mr. Hall had got it. In conclusion, he thought the Institution was much indebted to Mr. Hall for his extensive and valuable tables, which he (Mr. Spence) ventured to think would be rendered still more valuable by the few additions suggested.

On the motion of Mr. R. L. WEIGHTON the discussion was adjourned.

The PAST-PRESIDENT proposed a vote of thanks to Mr. J. P. Hall for his valuable paper, which was carried by acclamation.

NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS.

THIRD SESSION, 1886–87.

PROCEEDINGS.

NINTH GENERAL MEETING OF THE SESSION, HELD IN THE LECTURE HALL OF THE LITERARY AND PHILOSOPHICAL SOCIETY, NEWCASTLE-UPON-TYNE, ON WEDNESDAY EVENING, MAY 4TH, 1887.

W. THEODORE DOXFORD, ESQ., PRESIDENT, IN THE CHAIR.

ON account of the unavoidable absence of the Secretary, Mr. B. G. Nichol read the minutes of the last general meeting, held in Newcastle-upon-Tyne, on April 20th, which were approved by the members present, and signed by the President.

The PRESIDENT then called upon Mr. R. L. Weighton to continue the discussion on Mr. Hall's paper on "Compound *v.* Triple Expansion Engines from a Shipowner's point of view."

Mr. R. L. WEIGHTON said, the paper which was still before the meeting for discussion was of an eminently practical and useful character, and was peculiarly adapted for eliciting criticism and the expression of opinion. It was so adapted very largely by reason of the valuable tables of dimensions, results of trials, and general particulars which the writer gave, and for which he had certainly earned the best thanks of the Institution. There was one very important point in the paper which had been already referred to by Mr. Boyd and other speakers, and which appeared to require very particular notice, because, owing to the indefinite way in which it was treated it was apt to be misleading. He referred to the question of the relation between the *power* and the *weight* from which it was developed. He referred to that point, not because he deemed it to

be of paramount importance in the merchant service—in point of fact the question of weight of machinery was of very secondary importance in a large class of vessels—but for the sake of the general principles involved. On Table 1 there were given indicated powers and the corresponding weights of machinery for both the compound and triple class of engines, and the general deduction made from those particulars was that, power for power, the triples were about 5 per cent. lighter than the compounds. So far, so good. The table referred to certainly fully established that conclusion as regarded the particular instances given, but it did not warrant a general deduction which would be true in all cases; and when the writer proceeded on page 232 to indicate the explanation "why the weight was less in the triple compound as compared with the weight of the ordinary double compound," he raised the whole question in a very pertinent form. The explanation given in the paragraph referred to on page 232 for the difference in weight was that "the weight of steam required per indicated horse-power was much smaller in the case of the high-pressure triple than in that of the double compound." That might be true, or it might not be true, in a general sense, but it certainly was *not* the explanation of the difference in weight shown in the table. The real explanation was to be found in the table itself—in piston speed. By referring to Table 1, page 230, and taking the first five instances of both compounds and triples (he did not take more because the power was not given for more of the triples), it would be found that for the compounds the average stroke was 42 inches, and the average speed of piston was 442·4 feet per minute, whereas for the triples the average stroke was only 40·8 inches, and the speed of piston was as high as 493·68 feet per minute. That was a difference in piston speed of 11·6 per cent. in favour of the triples. Now assuming that the compound engines were driven at the same piston speed as the triple engines, the cylinders of the compound engines could be reduced in size for the required power; and it so happened that for the average of the five instances given in Table 1, that reduction in size of cylinders would lead to a reduction in the total weight of the compound engines of about 6 per cent., thus making the weights of the two classes of machinery practically equal in relation to the power. Moreover, considerations, *a priori*, would seem to point to the conclusion that increased pressures of steam did not, when manipulated with a view to economy of fuel (that is, when used in triple expansion engines), of themselves secure a saving of weight in machinery and water. It was only when those increased pressures were taken along with coal consumption that the total weight was diminished. Fuel economy of

high-pressure steam used by triple expansion engines was undoubted, and it was there, and there only, that weight economy in its widest sense could be looked for. But it might be contended that, owing to its working on three cranks, the triple expansion engine was adapted for running at a higher piston speed than the ordinary two-crank compound. True; but be it noted that the greater power thus obtained was due, not to the triple expansion principle and high pressures, but entirely to the existence of three cranks, and that a double expansion compound engine, using low-pressure steam, might be also run at the higher speed by using three cranks. It was, therefore, to be distinctly noted that, so far as the particulars given in Table 1 were concerned, the saving in weight which was there shown in favour of the triple expansion machinery could be accounted for entirely by speed of piston, and was not necessarily in any degree due to the adoption of high pressures and triple expansion. As regarded economy of fuel, there could be no question but that the triple expansion engine was an unqualified success, and Mr. Hall's tables afforded a very valuable confirmation of this. In speaking of the renewal of present engines, the author of the paper advocated a new intermediate and high-pressure cylinder, the low-pressure cylinder presumably remained as before. That, of course, would produce engines of considerably greater power than the replaced engines. Referring to the question of space occupied in the vessel, he thought it would be found that triple expansion three-crank engines would, along with their boilers, occupy a space greater in the aggregate than would be the case with similarly designed equivalent compound two-crank engines and their boilers. He meant space in a fore and aft direction. And if three-crank triple expansion engines were accommodated in the same space as the two-crank compound engines, it could only be by tolerating less vacant space between the machinery and bulkheads in the case of the triples than in the other. With regard to the sequence of cranks, he did not think this question was of much importance; so far as the ultimate economy of the engines was concerned it could have no appreciable effect. With the intermediate crank leading there would, of course, be less fluctuation of pressure on the receivers than was the case when the high-pressure was leading, but with large receivers this tendency was largely neutralised. As a matter of fact, he had a case recently in which the port engines were arranged with the intermediate crank leading, and the starboard engines were arranged with the high-pressure crank leading, and the result was such that at full power it was quite impossible to detect any difference in the indicator cards taken from the two engines.

Mr. Wm. Boyd said, he felt some reluctance in entering upon the discussion a second time, but he had consulted the President, who thought he would not be out of order in doing so. He had two objects in view, although he did not expect to be called upon so soon; one was to explain that his anxiety on the last occasion not to keep the attention of the meeting too long made him perhaps to some extent indefinite when he questioned Mr. Hall's theory that there was a saving of five per cent. in weight by the adoption of the triple expansion engines. He had endeavoured to show that the boilers, both in the case of the compound and triple expansion, would practically weigh the same. As Mr. Blechynden very properly pointed out, he had omitted to make special reference to the increased piston speed in the engines. Of course it was that increased piston speed, and the greater power obtained thereby, that enabled them to add the third cylinder, the additional weight of which was absorbed by the reduction of the weight in the remaining parts of the engines, the same power as originally existed being still maintained by increased piston speed. But his principal object in wishing to speak for a second time was that he ventured to submit that some opportunity should be taken to criticise a statement made by Mr. Marshall on the last occasion; that criticism, he hoped, would be supported; and if there were any shipowners there that evening, he should be very glad indeed if they would let them have their opinion. Mr. Marshall made a statement that his firm (and he involved all the rest of them) were prepared to construct engines "under ordinary commercial conditions" (he used Mr. Marshall's own words) at exactly half the weight as made at present: that was a very remarkable statement. He only regretted very much that Mr. Marshall was not present that evening, because he thought he ought to have had an opportunity of answering some questions that might be put to him. Mr. Marshall, in his remarks, referred to the engine to develop about 1,000 horse-power with about 220 tons as the total weight. Now, he again repeated what he said at the last meeting, that the weight of the boilers for the engines of that power, with water in them, would be something like 85 tons whether the engines were compound or triple expansion; so taking from the 220 tons (which was agreed upon as the weight of the ordinary triple expansion engine of that power) the above-named 85 tons as a constant, you have a remainder of 135 tons as the weight of the engines; therefore, he said that it was obviously a foregone conclusion that if the total weight of 220 tons was to be reduced to anything like 110 tons, as stated by Mr. Marshall as being possible, that something else must be reduced besides the engines themselves.

They therefore opened the door at once (a door which Mr. Marshall was no doubt prepared to open) of forced draught, or something else to increase the power of the boiler and reduce its weight. He was quite prepared to go a certain distance with Mr. Marshall, but in ordinary *commercial practice*—not torpedo catchers, not Government boats, not cruisers, but ordinary commercial practice—Mr. Marshall was prepared to reduce the engines 50 per cent. He thought he had shown them that to reduce it to anything like this they must adopt some system by which the power of the boilers would be very largely increased and the weight consequently reduced. That being so, it became a question how it was to be effected. He quite believed that the power of boilers could be to a very great extent assisted or promoted by the use of forced or assisted draught, yet when they talked of a reduction of 50 per cent., he must confess he thought they were wide of the mark. He had had some calculations made, and he would just name two points which he had arrived at. He had taken a pair of engines indicating 1,000 horse-power, $\frac{22'', 35'', \& 58''}{36''}$, with two boilers 12 ft. 6 in. and 10 ft. 6 in. These engines and boilers would weigh 220 tons; to reduce those engines and boilers to 110 tons, they would have to bring the engine down to the following sizes $\frac{18\frac{1}{2}'' \times 29'' \times 48''}{24''}$, with two navy-type boilers, about 7 ft. 6 in. diameter by 15 ft. 9 in. long, with the employment of forced draught. With these arrangements the total weight of the engines and boilers could be reduced to 110 tons. With regard to the speed of piston: whereas in the first case the engines would run at 75 revolutions, or a piston speed of 450 feet per minute, it would be necessary, in order to indicate 1,000 horse-power with the smaller engines, to run them at 160 revolutions, with a piston speed of 640 feet per minute. Now, if they took an ordinary cargo vessel, carrying 3,000 tons, into which engines 22″, 35″, and 58″ would be fitted, and they were to go to a shipowner and ask him to increase the price of those engines by something like 40 per cent., and to accept engines $\frac{18\frac{1}{2}'', 29'', \& 48''}{24''}$, with two locomotive boilers, accompanied by a system of forced draught in the stokehold, he doubted that would not be a very acceptable proposition. He did not enter into the question of the money value, but he thought they must try and avoid a mistake of trying to ride a good horse to death, and that to put small engines like these, running at 640 feet per minute, into a large cargo vessel, on a voyage to Bombay or across the Atlantic, would, he thought, be out of place.

Mr. TWEEDY said, he had been taken by surprise; he did not know he was to be called upon to speak. There were however one or two points which neither Mr. Weighton nor Mr. Boyd had referred to. The scheme of the paper appeared to him to be based on the assumption that the shipowner was not, as a rule, capable of distinguishing between the efficiency of the machinery and the hull. If this was the case, then he thought there was all the more reason why the paper should have clearly marked out this difference, so that the mistake of mixing up the ship with the machinery would be avoided in future. It is quite true Mr. Hall had made some such correction in Table 3, page 240, but on page 241 he says that although Table 3 is more correct, yet Table 2, is "near enough for the purpose." He, however, did not think it was sufficient for the purpose; generalisations of this kind were dangerous when based on quantities which have no real relation to the efficiency of the machinery. If they compared R and N, the efficiency of engine N was set down as 25 per cent. more than those of R, as measured by the quantity of cargo carried per ton of coal, but as a matter of fact the real consumption was 7 per cent. less, or a difference of about 30 per cent. due entirely to the difference of hull. The other point was that the tables would have been improved if instead of the gross dead-weight carried, including bunkers, the paying dead-weight had been taken as the quantity to be compared. He agreed, however, with previous speakers that their thanks were due to Mr. Hall for bringing before them so many interesting particulars.

Mr. SANDISON said, Mr. Hall at the outset of his paper submitted five questions for discussion, and despite sundry criticisms he thought he had answered them all satisfactorily with the exception, perhaps, of the fourth, viz.: "Will the life of the boilers be as long as that of those loaded to 80 or 90 pounds pressure per square inch?" Their experience with these high-pressure marine boilers was not sufficiently long for them to answer that question with any degree of certainty. Mr. Marshall, at the last meeting, strongly advocated the reduction of the usual Board of Trade factor of safety for the boilers of merchant ships, by some 20 per cent. He did not altogether agree with Mr. Marshall there. Speaking from a shipowner's point of view, he should be inclined to say that the reduction would not conduce to the longevity of the boiler, and would simply mean increased work for the manufacturer. The space occupied in the ship would not be any less, and the reduction in weight for any ordinary cylindrical boiler with water would not probably be much more than 10 per cent. With reference to the water supply for the boilers, it was very important, as Mr. Boyd suggested,

that a reserve tank for fresh water should be fitted or some equivalent adjunct, such as Weir's feed maker. If he remembered rightly steam was taken from the first receiver and used to evaporate salt water, the steam thus generated doing work in the low-pressure cylinder, while the water condensed from the first steam was passed into the hot well. He could not speak from experience, but he should think that an apparatus of that sort for an engine of any size would occupy a considerable amount of space. Take, for instance, one of Mr. Hall's boilers, K in Table 1, page 230, 13 feet diameter, 16 feet 6 inches long, with a heating surface of 2,730 square feet to develop 1,000 indicated horse-power. He supposed it would carry about 27 tons of water? Mr. Hall told them that the water was practically changed in 9 days—216 hours steaming. That gave them a supplementary feed of $\frac{27 \times 2{,}240}{216} = 280$ lbs. per hour; or, taking 15 lbs. of steam per indicated horse-power, a supplementary feed of $\frac{280 \times 100}{15 \times 1{,}000} = 1{\cdot}9$ per cent. The heating surface they would require to evaporate that quantity of feed water, according to ordinary practice, would be no less than 60 square feet for an engine of 1,000 indicated horse-power. He might say that he heard of a plan sometime ago of supplying fresh water, which had been carried out very successfully on a long voyage, by getting up steam in the donkey boiler to about 60 lbs. pressure and passing it into the first receiver. They there got the benefit of the steam generated in addition to the fresh feed, the deposit of course taking place in the auxiliary boiler only. He did not think it was uncommon to run a Bombay voyage without scumming or blowing, but a density of $2\frac{1}{4}$ at the end of the voyage was, he thought, uncommon, and said a great deal for the tightness of the engines and boilers generally; he should be inclined to say that $\frac{3}{32}$ was more like what they would find in average practice.

Mr. TAYLOR said he had no sympathy with Mr. Marshall's wish to reduce the weight of engines and boilers built of materials at present used, but if they were to have better materials, then, of course, weights might be reduced in proportion. His experience, particularly with boilers, instructed him not to reduce the Board of Trade or Lloyd's factor of safety. He thought the factor was quite low enough already; when they got a little corrosion on the furnace bottoms they were very soon led into costly repairs. Mr. Sandison thinks we have not sufficient experience to say anything of engines and boilers working with steam at 150 lbs. pressure. He might say that about a fortnight ago he saw the

first 150 lbs. pressure boiler of the ordinary construction that was ever put into a steamer, and that boiler was now five and a half years old. He knew for a positive fact that there had never been a tube touched in that boiler, nor, he thought, a combustion chamber stay either. The only real repair, as far as he knew, was that one of the furnace bottom plates was found to be laminated, and part of it had to be cut out. This boiler proved that they could make boilers at 150 lbs. pressure to stand as well as 80 lbs.; in fact, he considered they would last longer, and for this reason: in the old days, when 20 lbs. was the usual working pressure for boilers, with a factor of five, the boiler would probably explode at 100 lbs., but its elastic limit would be reached at about double its working pressure, *i.e.* at 40 or 50 lbs.; now the seams might easily be strained to an extra 20 lbs. by differences in temperature or other causes, and thus permanently injure the boiler. But with 150 lbs. working pressure the elastic limit would be between 300 and 400; it would thus take 150 or 200 lbs. extra pressure to approach the elastic limit. On that account the seams in the boiler would be kept in good condition, because the boiler did not feel the excessive strain, and he was quite sure that it would be a very bad boiler that did not run for twelve years. The only thing he took exception to in Mr. Hall's paper was that he did not allow for the different sizes of ships in which the double and triple cylinder engines were fitted. We find the average displacement of the ships having double cylinder engines to be 5,300 tons, while the ships having triple engines average 6,700 tons displacement. It is well known that the latter steamer per ton of displacement can be driven easier at a given speed than the former; if this had been allowed for, he thought the saving would have been less than 22½ per cent. in favour of the triple engines. He would like to make another remark about the wear and tear; he forgot to mention it at the proper place. In the "Claremont" (whose boiler he had previously mentioned) they had no trouble with the crank shaft or its bearings; they had not had a slide or a piston to face or a cylinder to bore.

Mr. HIRST said, he had not had the opportunity of being present at the last meeting and did not expect to be called upon to say anything. With regard to the life of boilers and the management of the triple engines, he thought that was about the most important point. The triple engine itself, if properly constructed, will take very little more looking after than the old compound engine, it was only a question of having the men in charge educated up to them. With regard to the wear and tear, he had seen and had had several opportunities of looking

at boilers, and he thought that the wear and tear was just about the same in the triple as in the compound, it depended very much on the men who had charge of the machinery. With reference to salting or deposit, that was a thing they wanted to pay special attention to. They all knew that it was upon long runs that the triple engine showed itself at its best. Perhaps in American voyages the triple engine would not show to such good advantage as in longer voyages; he thought the failures they had known had not been so much from the construction of the furnaces as the want of knowledge on the part of the men in allowing deposit to form. With regard to getting a scale upon those boilers, scale could not be formed by using soda; he did not believe they needed any soda or chemicals, he always discarded them, but soda would do no harm, neither would zinc. It depended very much upon the nerve of the men and their judgment to keep them tight, and avoid as little loss as possible. He would very much like to say something about the manipulation of the boiler; he thought himself that there was too much care spent, possibly in designing upon paper, the boiler to pass Lloyd's or Board of Trade, but at the same time, they ought to have the boiler constructed so that a man could get throughout; they could make the boilers so that a man could go through them, and why not do so? What he would like to say was that there should be good water spaces between furnaces and combustion chambers; they were too small as a rule. If they could have boilers so constructed, there was nothing to fear from the pressure they were going up to. With regard to joints, it all meant good plating and riveting, etc. With regard to crank shafts, he thought the three-crank engine was certainly an advantage in every way. The best crank was the built one, and should have keys fitted at all contracted parts. With regard to caulking of boilers, he thought they should try to make a boiler so that it would not need any caulking; if it did require any, then caulk it inside. He had surveyed compound boilers recently, made by several firms, fifteen years old, and they were still running at their original pressure, and from what he had seen of the triple he thought they would run for twenty years.

Mr. Wm. Menzies remarked that the treatment that suited a boiler at 90 lbs. would not suit a boiler at 150 lbs. That was his experience, and it was the experience of a great number of his friends who had triple expansion engines.

The President said he should like to express his regret at not being able to be present at the last two meetings, but he thought the Institution

had not suffered anything by his absence, as his place had been occupied by gentlemen better qualified than himself for the position. Unfortunately he was not present when the paper which they had just been discussing was read, but it had evidently given great satisfaction, and the writer had, perhaps with one exception, answered the questions which had been put at the beginning of the paper in such a manner as to meet with approval from all. Mr. Menzies however—who had certainly had considerable experience—appeared to differ from Mr. Hall and the other speakers upon the treatment of the boilers under higher pressures. He would now call upon Mr. Hall to reply.

Mr. HALL desired to tender his thanks to the members generally for the way in which his paper had been received, but especially to those gentlemen who had taken part in the discussion, and it gave him great pleasure to reply to their various remarks. First of all, Mr. Boyd was good enough to open the discussion, and to refer in kindly terms to his early connection with himself at Wallsend Slipway. In reference to Mr. Boyd's remarks *re* weights of engines, Mr. Boyd was under the impression that he had been too sanguine, and that the table of weights scarcely bore out the reduction of 5 per cent. as quoted. In support of this Mr. Boyd quoted H, I, and K, in Table 1, page 230, as being exaggerated in horse-power. To this he had only to say that the vessels under the letters H, I, and K had indicated the power with which they are credited for days. Taking K he had continually put this forth as capable of indicating 2,000 horse-power each day, and this had been done extensively, even with a heating surface of 2·78 square feet per indicated horse-power. The 3·2 to 3·4 square feet per indicated horse-power, given at the end of the paper, is on the everyday power or the ordinary work of the engines on voyage, 2·7 to 3 square feet being quite common and ample for the maximum horse-power as above quoted. Mr. Boyd treated this (Table 1) as representing the ordinary work of the engines at sea. It was scarcely that; it was more of a maximum or highest average indicated horse-power on the voyage. To make Table 1 more explicit he had added to the heading in column 10, so as to show that this column represented the maximum horse-power. The weights given by Mr. Marshall in his paper in 1882 of 480 lbs. per indicated horse-power was on the same basis, viz., that of the maximum average or full power average over the voyage. Mr. Boyd further quoted a boiler for 1,000 indicated horse-power as being 13 feet 6 inches diameter by 10 feet 6 inches long, 80 lbs. pressure for compounds, and a boiler 12 feet 6 inches diameter, by 10 feet 6 inches long,

150 lbs. pressure for the triples, and showed them to be equal in total weight, including water. Now, he was inclined to take a case from Table 1, letters C and I, where the dimensions of the boilers and the weights were as follows :—

	Ft.	In.		Ft.	In.		T.	C.	Q.
C = Boiler for Compound	14	0	×	10	6	=	97	14	0
I = Boiler for Triple ...	12	6	×	10	6	=	93	6	0

Or a saving in favour of the triple of 4 tons 4 cwts. This was equal to a reduction of 5 per cent. in the boiler department. His contention was that Table 1 should be taken as it stood, and that the reduction in weight was approximately about 5 per cent. in favour of the triples.

In reference to Mr. Nichol's remarks, he was glad to find that the figures given compared so favourably with his own views, and that he so fully endorsed the tables as given in the paper.

He was extremely obliged to Mr. Marshall for his kind reference to the value of the paper. He was sorry he could not go so far with him as a reduction of practically half the present weight in the ordinary mercantile engines. He quite thought that we might with assurance reduce the factor of safety in almost every part of the engines and boilers, that being based on the fact of having a material now in use carefully selected and *rigidly* tested: the factor of safety of to-day as compared with, say, 15 or 20 years ago, he admitted should have some consideration, due to the extra supervision and care in the selection of the materials used in the construction of our everyday work—but to come down to 250 lbs. per indicated horse-power, was a long stretch and such as he would not be inclined in the ordinary design to adopt. Anything much less than 400 to 450 lbs. would be something special in the design. We could get a reduction in the present weights by the adoption of a higher piston speed, but in the Mercantile Marine there was even a limit to that. The application of a fast running propeller to a heavy full cargo ship, was not a desirable thing. The inducement to reduce the machinery in ordinary cargo, hard worked vessels was not great. In machinery for war vessels the saving of weight was very valuable, and the tendency to-day was to come very low. Mr. Marshall had been doubtless very successful in that line. We had to get to-day in war vessels 20 indicated horse-power off every square foot of grate surface, as compared with about 16 indicated horse-power two years ago; Mr. Marshall had done something to bring this about. He should be very glad indeed to have particulars of Mr. Marshall's mercantile engines, when he got the weight down to 250 lbs. per indicated horse-power ; it would be most interesting and useful to all engineers.

In reference to Mr. Blechynden's remarks he quite agreed that there

was something in the reduction of the weight due to the extra piston speed in the case of the triple expansion engines. He thought also with him that in that line we might thus reduce the triples even further. We might, with assurance, in the mercantile marine go at a piston speed of 15 per cent. more than we had been in the habit of running with the ordinary compound engine—that is with three cranks. The vessels he had quoted with triple engines had an increased piston speed of from 8 to 12 per cent. over the compound. As to Mr. Blechynden's remarks re weights as quoted by Mr. Marshall in 1882; these on referring to the paper he would find were the maximum power on the voyage.

Mr. Crawford drew attention to several vessels in the table not bearing out the conclusions that the writer had put forth; now he thought with a little more careful looking into the table Mr. Crawford would see that the conclusions drawn were well founded; he took, in the first place, the average of each class of engines, compound and triple, and afterwards took them in such a way as to make it quite clear to his own mind that the conclusion arrived at of 22½ per cent. was fair and reasonable; and the difference of the vessels, as stated in the paper, page 236, was so slight that the equation referred to might be taken as fully applicable to the contents in Table 2. Mr. Crawford compared H and M and stated he thought that the comparison was unfair to the compound. He said, "because, while the triple engine with cylinders, $\frac{27'' - 44'' - 71''}{48''}$ was indicating 1,550 horse-power on presumably sixty revolutions and working probably at its maximum efficiency, the compounds with cylinders $\frac{40'' - 76''}{54''}$ was only indicating 1,100 horse-power on presumably under fifty revolutions and working probably at its maximum inefficiency." In reply he had to say that the maximum horse-power for these triple engines was 2,000 and the work done as per table was 1,550, or a difference of 22½ per cent. The compound engine maximum horse-power would be about 1,600, or as per table 1,110, or a reduction of 30 per cent. He (Mr. Hall) contended that the compound in this case had the best of it, due to the fact of having greater expansion of steam and more economical means of generating steam, the boilers having less work to do. Again, in comparing the vessel marked M, Mr. Crawford took the two voyages separately. This he contended was unfair. The writer of the paper took the longest time with this vessel of which he had information and put it down exactly as it was. He might have explained his reason why the second case of M or M^2, as Mr. Crawford called it, was a better

performance than the other; this was simply due to the fact that when the ship made the good performance she had been newly docked and cleaned, the remaining part of the work was done without having been previously in the dock; therefore he considered the mean of the two was the only fair way to look at this vessel; it was the mean on a long distance, which meant practically six months' work or two voyages to Bombay and back, and he therefore argued the way Mr. Crawford had compared the performances was unfair and of no real value. As suggested by Mr. Crawford he would append a list of the immersed midship girth of as many vessels as he could. He was afraid he would not be able to get the whole of them. (See Appendix I., page 274.)

Mr. Spence was quite right in assuming that Table 1 was largely a weight table. In reference to the heating and grate surface, he would find this given in Appendix 1, page 274. He thought he had really given quite enough when he gave the coal burnt, the distance steamed, and co-efficient of performances, etc., as in column 10, Table 2. This largely governed or qualified the other features of the performances; and he thought, from the standpoint of the paper, that was enough. As to the indicator cards, these were taken at different times on the voyage, the revolutions in the greater number of cases were taken by mechanical counters. The question of coal consumption was as per coal invoiced to owners. He would append also the midship section of as many cases as possible. He might say that certainly more than one-half the vessels quoted in Table 2 were under the care and control of a superintendent engineer, who managed and got returns very accurately. He would also add a table of weights (see Appendix II., page 274), separating the engines from the boilers, as asked for by Mr. Spence; he had taken two cases, D as compound, and J as triple, which he trusted might be of service to him.

He was very pleased to hear Mr. Weighton's speech that night, although it did not altogether agree with what he (Mr. Hall) had said as the source of the reduction of weights. He quite agreed that the piston speed was a big factor in the reduction of the weights, although notwithstanding that by Appendix II., page 274, he would find that even the boiler department was reduced something like five per cent., irrespective of what the engines might be reduced. He (Mr. Hall) said in his paper he had most strenuously advocated three cranks as being an element of success in the triple expansion engines. He was glad also to have Mr. Weighton's experience in reference to the sequence of cranks, as during this last three or four months a great discussion had been raised by mechanical engineers in reference to sequence of cranks. Beyond what

was due to the range of temperature, there was, in his opinion, not much in it, and the difference, if any, was in favour of the low-pressure leading. However, he considered that the greater power could be got out of the high-pressure leading, but for the question of economy, as stated in the paper, the low pressure leading was the most economical.

From Mr. Tweedy's remarks he thought he must have misread the paper, as certainly it was never intended to put forth that the shipowner was not capable of judging the difference between compound and triple engines or the qualities of the ship as against that of the engines. He felt satisfied that the shipowners were quite willing to receive information in reference to the adoption of the new type of engines. Mr. Tweedy thought it would have been better to take the dead-weight or the cargo carried as the basis for consideration; this the writer did not agree with, the performance of the engines was the amount of weight driven, and the weight of the ship could be easily determined from Table 2. He thought he had put the performances in the best way he knew, and was not disposed to agree with the remarks of Mr. Tweedy in reference to cargo carried.

In reply to Mr. Sandison's remarks, he thought the experience of Mr. Taylor would convince him that there had been quite enough information and experience with high-pressure boiler to form a fair and reliable opinion as to its life. Mr. Taylor did not believe in the factor of safety being reduced. Now, he (Mr. Hall) thought that the experience given by Mr. Taylor in his remarks in reference to the boiler that he had just a short time ago surveyed, the life of which was 5½ years, was an evidence or a reason why the factor of safety ought to be reduced; the whole of Mr. Taylor's speech went in favour of the reduction of the factor of safety rather than otherwise. In regard to the difference in displacement of compound and triples, he (Mr. Hall) was of opinion that it was clearly shown in Table 3 that a 1,000 tons displacement in a small ship took more driving than 1,000 tons in a large ship. Although Table 2 might show that triples were of the highest displacement, at the same time if Mr. Taylor would look at the cases taken separately he would find that almost invariably favour was shown to the compound, as on pages 236, 237, and 238. He would like also to state he had clearly pointed out in the paper that he considered that the compounds were fair and good examples of their class—not attempting to compare poor compounds with good triples, but rather the best of the compounds with the average triples.

What Mr. Hirst had said *re* wear ett d with

the purport of the paper, although he (the writer of the paper) should not be disposed to sympathise with boilers lasting so long as twenty years; this would be directly against the interests of the builders. Mr. Hirst thought that a scale could not be got by the use of zinc or soda. He (Mr. Hall) said in his paper "that a thin covering could be got by the use of zinc and soda;" also, on page 234, that "he had no sympathy with the practice of getting a heavy scale by salt deposits to protect the surfaces exposed to the action of the water."

Referring to the remarks of Mr. Menzies *re* his experience with triple expansion engines, he (Mr. Hall) was of opinion that the treatment of the one very much suited the other; at the same time, he considered there was a little more care required in the treatment of boilers of the higher pressure.

He again thanked the members for the attention they had accorded his paper, and he hoped that it, together with the discussion, would be of service to the Institution.

The PRESIDENT said he understood that the bulk of the speakers upon that paper were engineers, and they of course treated it from their standpoint. Now there were a great number of shipowners members of that Institution, and he was sure it would have given much pleasure to all had they likewise taken part in the discussion. Perhaps another year they would have the same subject brought up again, and, if so, it would be a great assistance to that Institution if shipowners would give their experience. He again thanked Mr. Hall on behalf of the members for his able paper.

NOTE.—In the tables introduced in Mr. Crawford's remarks on pages 254 and 255, the figures given under the columns headed "Saving in favour of Triple" are percentages.

APPENDIX I.

Vessel.	Mean Draft.	Area Immersed, Midship Section.	Girth of Midship Section.	Total Heating Surface in Boilers.	Total Grate Surface in Boilers.
	Ft. In.	Square Feet.			
A	21 5	780	73·32	4,990	144
,,	22 6¾	826	75·62	4,990	144
B	17 3¼	570	63·46	3,013	80
C	22 2	774	73·32	3,606	110
D	20 9¼	707	70·30	3,484	100
E	20 6	698	69·80	3,484	100
F	22 1¾	774	58·60	4,000	121
G	22 2½	851	76·92	.....	.....
H	22 2¼	850	76·88	.....	.....
,,	23 4½	900	79·25	.....	.....
I	.....	.....	.....	5,377	198
J	21 7	691	70.0	3,160	96
K	22 6	825	77·5	4,830	160
L	25 0	990	83·20	5,460	187·5
,,	24 7¾	975	82·50	5,460	187·5
M	23 3	915	79·68	5,460	187·5
,,	23 2	911·5	79·52	5,460	187·5
N	23 0	945	81·16	9,751	259·5
,,	25 1½	1,040	85·41	9,751	259·5
O	18 11¾	734·5	60·14	3,310	97·5
,,	19 4	748	60·86	3,310	97·5
Q	20 6½	734	71·32	2,396	86·5
R	18 1½	595	64·75	2,170	56
S	22 6	830	78	4,650	148
T	22 6	830	78	4,650	148

NOTE.—The above heating surface includes furnaces and combustion chambers down to centres of furnaces, and back and front tube plates.
The letters quoted, representing vessels, are the same as in Table II.

APPENDIX II.

DETAILED WEIGHTS OF COMPOUND AND TRIPLE EXPANSION ENGINES.

Letter on Table I.	Compound. D.	Triple. J.
	Tons.	Tons.
Boilers and all fittings in boiler room ...	88	90
Water in boilers	47	38
	135	128
Engines and shafting and all fittings in engine room and tunnel	121	107
Water in condenser, etc.	2	2
Total	258	237
Indicated horse-power	1,150	1,160
Lbs. per indicated horse-power	502	457
Reduction for triple	...	8·9 %

Taking compounds at 480 lbs. per indicated horse-power, the reduction to 457 lbs. for triple is equal to 4·79 per cent.

The PRESIDENT next called upon Mr. Boyd to move the amendments to the Articles of Constitution and Bye-Laws of which he gave notice at the last meeting.

Mr. W. BOYD moved that the following alterations to the Articles of Constitution and Bye-Laws be adopted, viz. :—

CONSTITUTION.

Art. IX.—Insert the words "an Honorary" before "Treasurer," line 4.

Art. X.—Insert the word "Honorary" before "Treasurer," lines 1 and 16.

Art. XIII.—Last paragraph to read, "They shall be eligible for office as Councilmen."

BYE-LAWS.

No. 7.—Erase present Bye-Law, and insert :—"On payment of each subscription the Secretary shall forward to the member an official receipt."

No. 11.—Page 6, line 5, insert "Honorary" before "Treasurer;" page 6, line 16, insert "Secretary" for "Treasurer."

Nos. 30, 31, and 32.—To read as one rule, as follows :—"The Secretary, who shall also act as Treasurer, shall be appointed by and act under the direction and control of the Council, and shall be paid such salary as the Council shall determine. He shall attend all meetings, Council and General, and shall take minutes of the proceedings, and enter them in proper books provided for the purpose. He shall write the correspondence of the Institution and Council, read minutes and notices at meetings, report discussions, and, if required by the Council, prepare papers for reading and publication, and read papers and communications at the meetings. He shall receive all payments due to the Institution, and shall bank the cash in hand whenever it amounts to ten pounds. The bank shall be determined by the Council, and the banking account shall be in the names indicated in connection with the Finance Committee. He shall keep a cash account book, general and detail, which shall on all occasions be open to inspection by the Finance Committee or by the Council. He shall keep a register of the names of members, so arranged as to distinguish all members whose subscriptions are in arrear. He shall also perform whatever other duties are indicated in the Bye-Laws of the Institution as appertaining to his department; and shall remain in office during the pleasure of the Council. He shall not vote on any resolution."

NOTE.—The number of the Bye-Laws after the above to be altered.

No. 33.—Insert the word "Honorary" before the word "Treasurer" whenever named.

No. 36.—Erase present Bye-Law, and insert:—"Copies of papers to be read during any session will be sent seven days before the date of reading to members who shall have applied to the Secretary for them, in writing, at the commencement of the session. The discussion on a paper shall not be considered closed on the evening on which it is read, but shall be open for renewal at a subsequent meeting, prior to the reading of the paper set down for that date."

Mr. TAYLOR seconded the adoption of these alterations, which was carried unanimously.

Mr. MENZIES proposed that Bye-Law 18 should read as follows:—"The President shall be chairman at every meeting, and in his absence, one of the Past Presidents or one of the Vice-Presidents; or in the absence of all the Vice-Presidents, a Councilman shall take the chair; or if no Councilman be present and willing to take the chair, the meeting shall elect a Chairman."

This was seconded by Mr. HALL, and carried unanimously.

The PRESIDENT then declared the result of the ballot for the officers for the ensuing year as under. He had to announce that he had had the honour of being re-elected for the second year: he could only promise that he should do what he could in the future as he had in the past to further the interests of the Institution:—

President.—W. THEO. DOXFORD.

Vice-Presidents.—B. C. BROWNE, H. F. SWAN.

Councilmen.—W. J. BONE, W. KILVINGTON, F. C. MARSHALL, JAS. REDHEAD, PHILIP WATTS.

Hon. Treasurer.—B. G. NICHOL.

Mr. R. L. WEIGHTON moved that Mr. R. W. SISSON be re-appointed Auditor, Mr. HALL seconded, and it was carried unanimously.

Mr. WM. BOYD said, it must be obvious to all of them that there was one resolution that must be put, and he modestly thought that he was the fittest person to move that resolution, and that was to propose a hearty vote of thanks to their President for his services during the past year. He was quite sure of one thing, that, though he might not be able to give proper expression to the feelings of the members generally, no one understood better than himself the work that Mr. Doxford had gone through during the past year. There was one point which he wished specially to mention, viz., that Mr. Doxford had, without the least scruple,

without the least hesitation, made himself as it were a Newcastle man during his term of office. It was all very easy for them who lived in Newcastle to come down there, but to come over from a neighbouring borough, during the winter months, not only to the general meetings but to the Council meetings, meant a very great sacrifice of his personal convenience. He was sure they appreciated it. Mr. Doxford's kindness and courtesy during the past session had been notorious, and he begged them to join him in proposing a vote of thanks to Mr. Doxford.

Mr. C. W. HUTCHINSON said, he rose with very great pleasure to second the proposition, and he thought it spoke very much indeed for Mr. Doxford's attachment to that Institution to have allowed himself to be nominated for another year of such hard work.

Carried with acclamation.

The PRESIDENT said, he always felt it a difficult matter to reply to a vote of thanks. It always seemed to him that one got more credit than one deserved for the little services rendered. He was only too glad to do all he could to further the interests of the Institution. The incoming year would be a very important one for that Institution, as the Institution of Naval Architects had accepted the invitation to visit Newcastle and Sunderland this summer. He need not say that a great deal would depend not only upon the President but also upon the members of that Institution to make those meetings successful, and he trusted to receive from all their cordial support. He believed that the Naval Architects expected that they would provide some of the papers which were to be read. If, therefore, any member was prepared to read a paper they would be very glad to receive notice at once. It was also very important that papers for their own next session should be taken in hands early so that they might be distributed in good time. He did not think that they had had a paper in due time during the past session, and this rendered it quite impossible for the Council to carry out the arrangements for the meetings as satisfactorily as they wished to do. He would especially appeal to the members from Sunderland to offer papers, for he felt that they had not done what they ought to have done in the past. He believed they had the talent and ability to produce papers as welcome to that Institution as any they had yet had. Let them therefore do so and thus put Sunderland into the position it should hold. The Council would be glad of papers upon practical details of ship and engine construction, for which there was plenty of room and which could be well prepared by many members who could not trust themselves to deal with the higher theoretical subjects. There was another subject

that he would like to mention and that was the apparent apathy of members regarding the election of members of Council, etc. It could hardly be a satisfactory state of affairs when less than 25 per cent. of the members took the trouble to return the voting papers as was the case this week. For his own part he would rather have seen 75 per cent. of papers returned even if the result had been the election of another President, for it would have shown that the great bulk of the members were taking a direct interest in the management of the Institution, and that would have been the best possible guarantee for its future success. He again thanked them for their kindness. He then declared the third session of the Institution closed.

APPENDIX.

REFERENCES.

PUBLIC BUILDINGS, &c.

1. Wood Memorial Hall, and Literary and Philosophical Society.
2. Town Hall.
3. Exhibition.
4. Central Railway Station.
5. Blyth and Tyne Railway Station.
6. General Post Office.
7. St. Nicholas' Cathedral.
8. The Castle.
9. Black Gate and Antiquarian Museum.
10. Quayside.
11. Swing Bridge.
12. Commercial Exchange and News Room.
13. Public Library.
14. Central Exchange and Art Gallery.
15. Museum of Natural History Society.
16. Theatre Royal.
17. Tyne Theatre.

HOTELS AND CLUBS.

18. Station.
19. County.
20. Douglas.
21. Turf.
22. Turk's Head.
23. Royal Exchange.
24. Central Exchange.
25. Alexandra.
26. Crown.
27. Union Club.
28. Northern Counties Club.
29. Newcastle Liberal Club.
30. Northern Conservative Club.

WORKS IN NEWCASTLE.

31. Sir W. G. Armstrong, Mitchell, & Co., Ordnance Works and Shipyard.
32. R. Stephenson & Co., Engine Works.
33. Hawthorn, Leslie, & Co., Ltd., Engine Works.
34. J. & G. Joicey, Engine Works.
35. Donkin & Nichol, Engine Works.
36. E. Scott & Co., Engine Works.
37. Walker, Parker, Walker, & Co., Lead Works.
38. Tyne Forge Co.

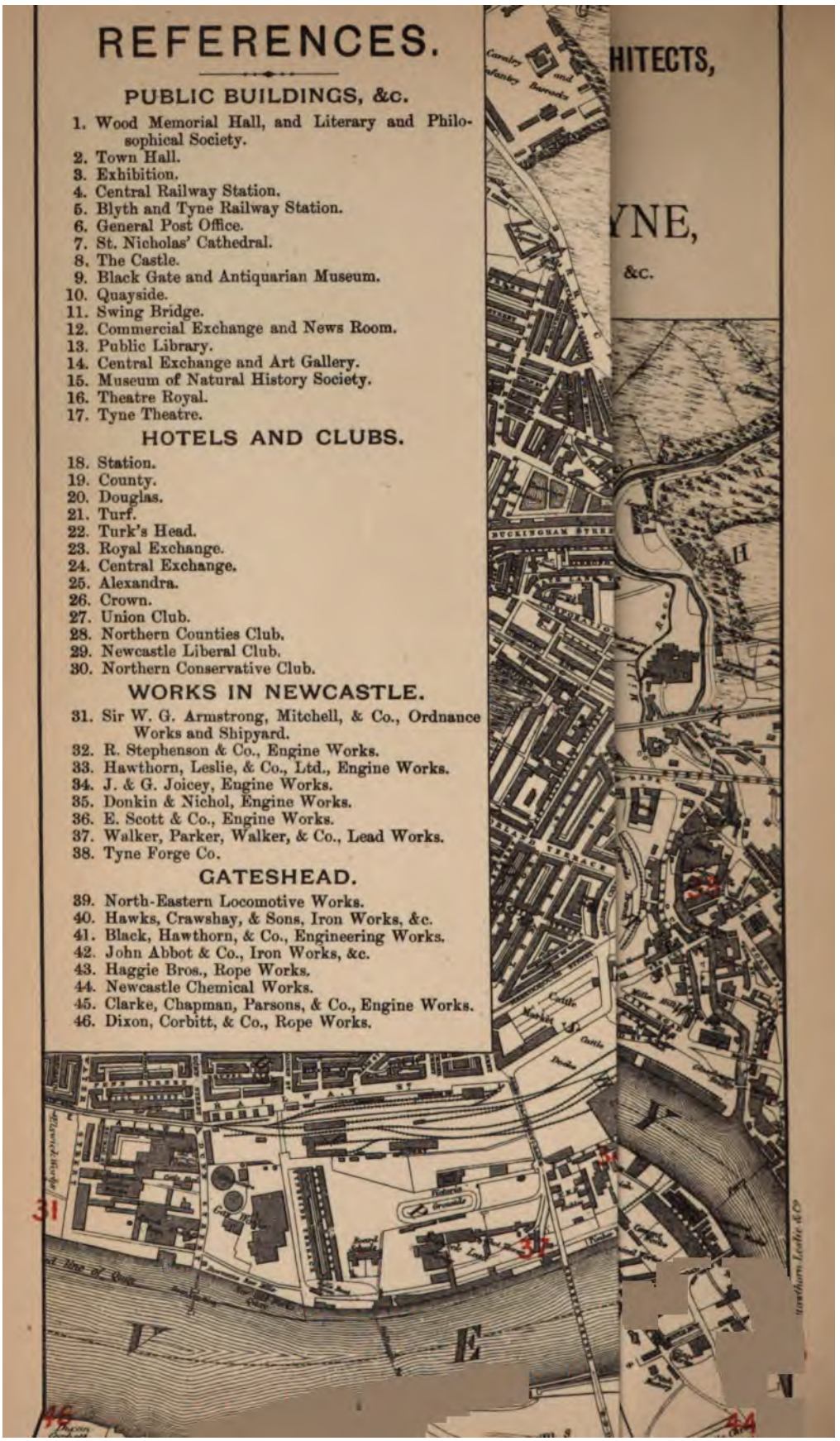
GATESHEAD.

39. North-Eastern Locomotive Works.
40. Hawks, Crawshay, & Sons, Iron Works, &c.
41. Black, Hawthorn, & Co., Engineering Works.
42. John Abbot & Co., Iron Works, &c.
43. Haggie Bros., Rope Works.
44. Newcastle Chemical Works.
45. Clarke, Chapman, Parsons, & Co., Engine Works.
46. Dixon, Corbitt, & Co., Rope Works.

HITECTS,

YNE,

&c.



Institution of Naval Architects.

NEWCASTLE-UPON-TYNE MEETING,

July 26th, 27th, 28th, and 29th,

1887

GENERAL PROGRAMME,

WITH MAPS AND OTHER LOCAL INFORMATION.

Newcastle-upon-Tyne:
ANDREW REID, PRINTING COURT BUILDINGS, AKENSIDE HILL

1887.

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PLANS—Newcastle-on-Tyne.

Sunderland.

Exhibition.

Palmer's Shipbuilding and Iron Co.'s Works.

Consett Ironworks.

Elswick Works.

River Tyne.

SPECIAL NOTICES.

The Wood Memorial Hall, Neville Street, Newcastle, will be open to Members from 9 a.m. to 1 p.m. and from 3 to 6 p.m., on the Tuesday, Wednesday, and Thursday; and from 9 to 11 a.m. on Friday, for the reception of Letters, issue of Programmes, Members and Visitors' Cards, etc.

Railway and Luncheon Tickets can be obtained by Members of the Institution on application to the Hon. Secretary, Mr. John Duckitt.

During the Meetings, letters for the Secretary of the Institution of Naval Architects should be addressed to the **Wood Memorial Hall, Neville Street, Newcastle.**

The Library and Reading Room of the Literary and Philosophical Society has been kindly placed at the disposal of the Members of the Institution of Naval Architects during their visit.

Two Excursions are set down for Thursday. Members can choose which they will take. Members going to Jarrow can, if they desire, return by ordinary Train to Newcastle (1st class fare, 1s.). Members going to Low Walker can, if they desire, return by ordinary Train to Newcastle from either Low Walker or Wallsend Stations (1st class fare, 7d.).

The Executive Council of the Exhibition have kindly allowed tickets to be issued to the Members of the Institution, admitting them to the Exhibition at all times on July 26th, 27th, and 28th. (*Pink Ticket.*)

☞ **It is absolutely necessary that the times set down for the various Excursions should be strictly adhered to throughout.**

☞ **Visitors and Members are requested to sign their names upon the various Luncheon Tickets, and give them up to the attendants at the doors of the Luncheon Halls on entering.**

Offices of the Institution of Naval Architects:

5, ADELPHI TERRACE, LONDON, W.C.

GEORGE HOLMES, ESQ., *Secretary.*

Offices of the North-East Coast Institution of Engineers and Shipbuilders:

6, EXCHANGE BUILDINGS, KING STREET, NEWCASTLE-ON-TYNE.

JOHN DUCKITT, ESQ., *Secretary.*

INSTITUTION OF NAVAL ARCHITECTS.

OFFICERS OF THE INSTITUTION FOR 1887.

President.

THE RIGHT HON. THE EARL OF RAVENSWORTH.

Vice-Presidents.

H.R.H. The Duke of Edinburgh, K.G., K.T., K.P., G.C.S.I., G.C.M.G., K.C.B., Vice-Admiral.
The Right Hon. The Earl of Northbrook, G.C.S.I.
The Right Hon. Lord Brassey, K.C.B.
The Right Hon. Lord George Hamilton, M.P.
The Right Hon. Lord John Hay, G.C.B., Admiral.
The Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Admiral.
The Right Hon. Sir Cooper Key, G.C.B., F.R.S., Admiral.
The Right Hon. W. H. Smith, M.P.
The Hon. Arthur Duncombe, Admiral.
Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.
Sir Nathaniel Barnaby, K.C.B.
Sir F. J. Bramwell, F.R.S.
Sir Alexander Milne, Bart., G.C.B., Admiral of the Fleet.
Sir Frederick W. E. Nicolson, Bart., C.B., Admiral.
Sir James Ramsden, Kt.
Sir E. J. Reed, K.C.B., F.R.S., M.P.
Sir Robert Spencer Robinson, K.C.B., F.R.S., Admiral.
Thomas Brandreth, Vice-Admiral.
F. K. Barnes, Esq.
Peter Denny, Esq., F.R.S.E.
Henry Green, Esq.
Benjamin Martell, Esq.
George W. Rendel, Esq.
W. H. Tindall, Esq.
Bernard Waymouth, Esq.
W. H. White, Esq.
James Wright, Esq., C.B.
Joseph Woolley, Esq., M.A., LL.D.

Members of Council.

Walter Brock, Esq.
James Dunn, Esq.
Francis Elgar, Esq., LL.D., F.R.S.E.
J MacFarlane Gray, Esq.
Sir E. J. Harland, Bart.
R. H. Humphrys, Esq.
John Inglis, Esq., Jun.
William John, Esq.
Alexander C. Kirk, Esq.
James Laing, Esq.
Henry H. Laird, Esq.
Frank C. Marshall, Esq.
J. T. Milton, Esq.
Henry Morgan, Esq.
William Parker, Esq.
John Price, Esq.
George Banks Rennie, Esq.
John Scott, Esq.
Richard Sennett, Esq.
William E. Smith, Esq.
J. Rodger Thomson, Esq.
John I. Thornycroft, Esq.
Phillip Watts, Esq.
Henry H. West, Esq.
A. F. Yarrow, Esq.

Associate Members of Council.

The Most Hon. the Marquis of Ailsa.
John Corry, Esq.
Prof. J. H. Cotterill, F.R.S.
Commander R. N. Custance, R.N.
George Duncan, Esq.
R. E. Froude, Esq.
Dixon Kemp, Esq.
Captain G. H. Noel, R.N.

Treasurer.

Henry Green, Esq. (Vice-President.)

Auditors.

John Corry, Esq. (Associate Member of Council.)
E. A. Cowper, Esq. (Associate.)

Secretary.

George Holmes, Esq.

VISIT OF THE INSTITUTION OF NAVAL ARCHITECTS.

THE NORTH-EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS having invited the Institution of Naval Architects to visit this district and hold a Summer Session in Newcastle-upon-Tyne and Sunderland, and the invitation having been accepted, the following gentlemen were appointed an Executive Committee to make the necessary arrangements for the intended visit:—

W. T. Doxford, Esq., *Chairman.*
W. Boyd, Esq.
W. J. Bone, Esq.
H. Charlton, Esq.
J. P. Hall, Esq.
A. Laing, Esq.
H. Macoll, Esq.
F. C. Marshall, Esq.
J. Price, Esq.
R. Readhead, Esq.
A. Taylor, Esq.
R. Thompson, Esq.
J. Tweedy, Esq.
P. Watts, Esq.
R. L. Weighton, Esq.
J. Duckitt, Esq., *Hon. Secretary.*

GENERAL RECEPTION COMMITTEE.

Council of North-East Coast Institution of Engineers and Shipbuilders, as under:—

President.

W. Theo. Doxford, Esq.

Past-President.

W. Boyd, Esq.

Vice-Presidents.

Sir B. C. Browne.
A. Coote, Esq.
J. Price, Esq.
Wigham Richardson, Esq.
H. F. Swan, Esq.
A. Taylor, Esq.

Councilmen.

W. J. Bone, Esq.
H. Charlton, Esq.
J. P. Hall, Esq.
C. W. Hutchinson, Esq.
W. Kilvington, Esq.
Arthur Laing, Esq.
F. C. Marshall, Esq.
James Readhead, Esq.
M. Sandison, Esq,
W. G. Spence, Esq.
J. C. Stirzaker, Esq.
Robert Thompson, Esq.
J. Tweedy, Esq.
P. Watts, Esq.
R. L. Weighton, Esq.

B. G. Nichol, Esq., *Honorary Treasurer.*
J. Duckitt, Esq., *Secretary and Treasurer.*

GENERAL RECEPTION COMMITTEE.—CONTINUED.

Sir Benjamin C. Browne, Mayor of Newcastle-on-Tyne.
W. H. Stephenson, Esq., Sheriff of Newcastle-on-Tyne.
E. Richardson, Esq., Mayor of Sunderland.
G. Davidson, Esq., Mayor of Gateshead.
J. T. Eltringham, Esq., Mayor of South Shields.
J. Elliot, Esq., Mayor of Tynemouth.
T. S. Salter, Esq., Mayor of Jarrow.
Sir Charles Mark Palmer, Bart., President of Newcastle and Gateshead Chamber of Commerce.
J. C. Stevenson, M.P., Esq., Chairman of River Tyne Improvement Commissioners.
James Laing, Esq., Chairman of River Wear Commissioners.
P. J. Messent, Esq., C.E., Engineer to River Tyne Improvement Commissioners.
H. H. Wake, Esq., C.E., Engineer to River Wear Commissioners.
Sir Lowthian Bell, President of North of England Institute of Mining and Mechanical Engineers.
Professor W. Garnett, M.A., D.C.L., Principal of Durham College of Physical Science.
Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Cragside, Rothbury.
S. P. Austin, Esq., Wear Shipyard, Sunderland.
J. S. Barwick, Esq., Sunderland.
W. Black, Esq., Messrs. Black, Hawthorn, & Co., Gateshead.
W. Boyd, Esq., Messrs. Wallsend Slipway & Engineering Co.
T. B. Briggs, Esq., Sunderland.
Ralph Carr, Esq., Newcastle.
H. Clark, Esq., Mr. G. Clark, Southwick, Sunderland.
G. Cleugh, Esq., Messrs. Tyne Iron Shipbuilding Co., Willington Quay.
G. Crawshay, Esq., Haughton Castle.
W. Cross, Esq., Messrs. R. & W. Hawthorn, Leslie, & Co., Forth Banks.
J. H. W. Culliford, Esq., Sunderland.
W. Denton, Esq., Messrs. Palmer's Shipbuilding & Iron Co., Jarrow.
W. Dickinson, Esq., Mr. John Dickinson, Sunderland.
W. Dickinson, Esq., Newcastle.
R. P. Doxford, Esq., Messrs. W. Doxford & Sons, Sunderland.
E. Eccles, Esq., Newcastle.
J. Fisher, Esq., Newcastle.
R. H. Gayner, Jun., Esq., Sunderland.
J. L. Gracie, Esq., Newcastle.
W. Hepple, Esq., Messrs. W. Hepple & Co., North Shields.
R. M. Hudson, Esq., Sunderland.
J. H. Irwin, Esq., North-East Marine Engineering Co., Sunderland.
W. Jenkins, Esq., Consett Iron Co.
James Laing, Jun., Esq., Deptford Shipyard.
A. de Launde Long, Esq., Messrs. Dorman, Long, & Co., Middlesborough.
G. E. Macarthy, Esq., Newcastle.
John Macintyre, Jun., Esq., Newcastle.
H. Macoll, Esq., Wear Shipyard, Sunderland.
J. D. Milburn, Esq., Newcastle.
C. Mitchell, Esq., Jesmond Towers, Newcastle.

GENERAL RECEPTION COMMITTEE.—CONTINUED.

Henry Nelson, Esq., Newcastle.
T. Pinkney, Esq., Sunderland.
John Readhead, Esq., Messrs. John Readhead & Co., South Shields.
G. Renwick, Esq., Messrs. Pontoons & Dry Dock Co., Wallsend.
G. Roberts, Esq., Newcastle.
J. Rogerson, Esq., Croxdale Hall, Durham.
W. H. Scott, Esq., Newcastle.
E. Scott, Esq., Messrs. Ernest Scott & Co., Newcastle.
R. Shadforth, Esq., Sunderland.
J. Y. Short, Esq., Messrs. Short Brothers, Sunderland.
J. W. Spencer, Esq., Messrs. John Spencer & Co., Newburn.
W. D. Stephens, Esq., Newcastle.
F. S. Strickland, Esq., Newcastle.
S. Tatham, Esq., Messrs. Hawks, Crawshay, & Sons, Gateshead.
J. Temperley, Esq., Newcastle.
J. L. Thompson, Jun., Esq., Messrs. J. L. Thompson & Sons, Sunderland.
R. Thompson, Esq., Messrs. Robert Thompson & Sons, Sunderland.
H. Watson, Esq., Messrs. Henry Watson & Co., Newcastle.
R. Welford, Esq., Tyne Steam Shipping Co., Newcastle.
P. G. B. Westmacott, Esq., Elswick Works, Newcastle.

LIST OF FIRMS CONTRIBUTING TO THE EXPENSES OF THE EXECUTIVE COMMITTEE.

Armstrong, Sir W. G., Mitchell & Co.
Austin, S. P., & Co.
Black, Hawthorn, & Co.
Clark, George
Consett Iron Co.
Dickinson, John.
Dorman, Long, & Co.
Doxford, W., & Sons.
Hawthorn, R. & W., Leslie, & Co.
Hawks, Crawshay, & Sons.
Hepple, W., & Co.
Laing, James.
North-Eastern Marine Engine Works Co.
Palmer's Shipbuilding & Iron Co.
Readhead, John, & Co.
Richardson, Wigham, & Co.
Scott, Ernest, & Co.
Short Brothers.
Spencer, John, & Sons.
Thompson, J. L., & Sons.
Thompson, Robert, & Sons.
Tyne Iron Shipbuilding Co.
Tyne Pontoon & Dry Dock Co.
Wallsend Slipway & Engineering Co.
Watson, H., & Sons.

Institution of Naval Architects.

SUMMER SESSION

AT

NEWCASTLE-ON-TYNE AND SUNDERLAND,

1887.

THE RIGHT HONOURABLE THE EARL OF RAVENSWORTH,

President of the Institution, will occupy the Chair.

The Meetings will be held as follows:—

ON TUESDAY, JULY 26TH.

At the Hall of the Literary and Philosophical Society (kindly lent for the occasion), Westgate Road, Newcastle-on-Tyne, at 10 a.m. punctually.

ON WEDNESDAY, JULY 27TH.

At the Hall of the Subscription Library, Fawcett Street, Sunderland, at 10 a.m. punctually.

ON THURSDAY, JULY 28TH.

At the Hall of the Literary and Philosophical Society, Westgate Road, Newcastle-on-Tyne, at 10 a.m. punctually.

ON FRIDAY, JULY 29TH.

Excursion to Consett, to visit the Consett Iron and Steel Works.

(Admission to the above by Member or Visitor's Ticket.)

Programme of Proceedings.

Tuesday, July 26th.

10·0 a.m.—MORNING MEETING at the Hall of the Literary and Philosophical Society, Westgate Road, Newcastle-on-Tyne, at 10 a.m. punctually.

Official Reception of the Institution by the President and Council of the North-East Coast Institution of Engineers and Shipbuilders, the Mayor of Newcastle, and the General Reception Committee.

ADDRESS by the President, THE RIGHT HON. THE EARL OF RAVENSWORTH.

The following Papers will then be read and discussed :—

1. "ON THE APPLICATION OF HYDRAULIC PRESSURE TO NAVAL GUNNERY." By the Right Hon. Lord ARMSTRONG, C.B., D.C.L., LL.D., F.R.S. (Vice-President), and J. VAVASSEUR, Esq., Associate.

2. "RECENT DEVELOPMENTS IN MARINE ENGINEERING." By FRANK C. MARSHALL, Esq., Member of Council.

12·30 p.m.—Leave by Special Conveyances (free) from the Hall to Elswick Shipyard. (Admission by Special Card only.)

1·0 p.m.—Luncheon at Elswick on the Invitation of Messrs. Sir W. G. Armstrong, Mitchell, & Co. (Admission by Invitation Card.)

2·15 p.m.—Inspection of Messrs. Sir W. G. Armstrong, Mitchell, & Co.'s Works and Shipyard, at Elswick. (See page 302 and Plan.)

4·30 p.m.—Return from Elswick by Special Conveyances to Central Station, Newcastle.

(The evening of this day will be without engagements.)

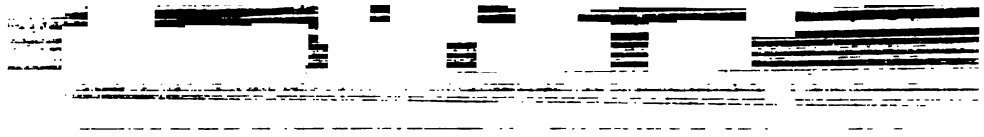
Wednesday, July 27th.

9·15 a.m.—A Special Train (by free railway ticket) will leave the Central Station, Newcastle, for Sunderland, calling at Gateshead.

10 a.m.—MORNING MEETING at the Hall of the Subscription Library, Fawcett Street, Sunderland, at 10 a.m. punctually.

Official Reception of the Institution by the Mayor, Shipbuilders, and Engineers of Sunderland.

VISIT
1¾
1½
1¼
HOLY ROCK
E RADIUS
ROKER PIER
ARMSTRONG & Co
J. BLUMER & Co
J.L. THOMPSON & SONS
HARBOUR ENTRANCE
STRAND SLIP
OSBORNE GRAHAM SHIP BUILDERS
W E A R
SOUTH DOCKS
Nº EASTERN MARINE ENGINEERING Cº
SUNDERLAND SHIP BUILDING Cº
BARTRAM HASWELL
HYLTON RAILWAY STATION
SOUTH OUTLET
HENDON DOCK
WEAR FUEL WORKS
N.E. RAILWAY
HENDON GAS WORKS
HENDON PAPER WORKS
By Permission of the River W



The following Papers will be read and discussed:—

1. "On some recent Experiments with Basic Steel." By W. H. White, Esq., Director of Naval Construction, Vice-President.
2. "On the present Position occupied by Basic Steel, for Shipbuilding." By B. Martell, Esq., Chief Surveyor to Lloyd's Register of British and Foreign Shipping, Vice-President.

12·45 p.m.—Luncheon in the New Assembly Hall, Fawcett Street, Sunderland, on the invitation of the General Committee. (*Buff Ticket.*)

2 p.m.—The party will drive by Special Conveyances (free) to the Chain Cable and Anchor Testing Works of the River Wear Commissioners, South Dock, which will be seen in operation. (Admission by Member and Visitor's Ticket.) (See Plan of Sunderland.)

3·0 p.m.—Depart from North Tidal Basin by Steam Tug (kindly provided by the Commissioners) for Roker Pier Works.

4·50 p.m.—Leave Roker by Special Conveyances (free) for Central Railway Station.

5·20 p.m.—Return from Central Station, Sunderland, by Special Train to Gateshead and Newcastle.

8 p.m.—Conversazione and Reception by invitation of Sir Benjamin C. Browne, Mayor of Newcastle, and Lady Browne, at the Royal Mining, Engineering, and Industrial Exhibition, Newcastle. (The Reception will take place in the Art Gallery, South Court. Evening Dress.)

Thursday, July 28th.

9·45 a.m.—The Council of the Institution will meet in the small room of the Literary and Philosophical Society, Westgate Road, Newcastle-on-Tyne, to recommend the Election of Candidates as Members and Associates.

*** *Members having Candidates to bring forward for election are requested to send their proposal forms to the Secretary as soon as possible.*

10 a.m.—Meeting of the Members at the Hall of the Literary and Philosophical Society, Westgate Road, Newcastle-on-Tyne, for the Election of Members and Associates, and for the transaction of other formal business.

The following Paper will be read and discussed :—

"TYNE IMPROVEMENTS." By P. J. MESSENT, Esq., C.E., Engineer to River Tyne Commissioners.

The Debate on Mr. F. C. MARSHALL'S Paper will then be resumed.

12·30 p.m.—Luncheon in the Town Hall, Newcastle-on-Tyne, on the invitation of the General Committee. Entrance from Cloth Market. (*Blue Ticket.*)

EXCURSION No. 1.—(By Member or Visitor's Ticket.) See Plan of River Tyne.

1·50 p.m.—Leave Fish Quay by Special Steamer, "J. C. Stevenson" (kindly provided by the Tyne Commissioners), for Jarrow.

2·25 p.m.—Arrive at Messrs. PALMERS Shipbuilding and Iron Co.'s Works. Inspect the Works. (See page 300 and Plan.)

4 p.m.—Depart by Steamer.

4·30 p.m.—Arrive at North Pier, Tynemouth.

5·15 p.m.—Return by Special Train (by free railway ticket) from Tynemouth.

5·35 p.m.—Arrive at Central Station, Newcastle.

EXCURSION No. 2.—(By Member or Visitor's Ticket.) See Plan of River Tyne.

1·50 p.m.—Leave Fish Quay by Special Steamer, "Alice" (kindly provided by John Rogerson, Esq., Croxdale Hall, Durham), for Low Walker.

2·15 p.m.—Arrive at Low Walker. Inspect the Shipyard of Messrs. Sir W. G. ARMSTRONG, MITCHELL, & Co. ; also the Shipyard and Engine Works of Messrs. WIGHAM RICHARDSON & Co.

3·45 p.m.—Depart from the latter yard.

4·30 p.m.—Arrive at the North Pier, Tynemouth.

5·15 p.m.—Return by Special Train (free) from Tynemouth.

5·35 p.m.—Arrive at Central Station, Newcastle.

7 p.m.—Dinner of the Institution at the Newcastle Exhibition, Tickets, 7s. each, exclusive of Wine. Morning Dress. Tickets will be paid for at the Dinner. Members are at liberty to invite their friends to the Dinner.

*** *Members intending to be present are particularly requested to give early notice to the Secretary of the Institution, 5, Adelphi Terrace, London, W.C., stating the number of Tickets they will require.*

(A description of the Exhibition will be found on page 295.)

Friday, July 29th.

9·55 a.m.—Leave Central Station, Newcastle, for Consett by Special Train (by free railway ticket).

10·35 a.m.—Arrive at Consett, and inspect the Iron and Steel Works of Messrs. THE CONSETT IRON Co. (Admission by Member or Visitor's Ticket.) (See page 301 and Plan for route.)

(Should a number of the visitors desire to inspect the Brick Works, marked K on Plan, and which are a short distance from the Main Works, a party will be organised to visit them.)

1·15 p.m.—Luncheon by invitation of Messrs. THE CONSETT IRON Co., in the Town Hall, Consett. (Admission by Invitation Card, *Green*.)

3·40 p.m.—Leave Consett by Special Train (free) for Newcastle.

N.B.—Visitors desiring to return South can leave Consett by 3·25 p.m. Train, due in Durham at 4·5, to catch the South Train leaving Durham at 4·21.

WORKS OPEN FOR INSPECTION.

(BY MEMBER'S CARD ONLY. FOR POSITION, SEE PLAN OF SUNDERLAND.)

NAME.	PLACE.	NATURE OF WORKS.	WHEN OPEN.
Austin, S. P., & Co.	Sunderland	Shipbuilding and Repairing	Each day, 10 to 4.
Ayre's Quay Bottle Works...	do.	Bottle Works	,,
Clark, George	do.	Engineering	,,
Dickinson, John	do.	Marine Engine Works ...	,, 10 to 4.
Doxford, W., & Sons ...	do.	Shipbuilding...	,, 10 to 4.
Greener & Co.	do.	Flint Glass Works	,, 10 to 4.
*Hendon Paper Works Co. ...	do.	Paper Works...	,, 10 to 4.
Laing, James	do.	Shipbuilding...	For such time as most convenient.
River Wear Commissioners...	do.	... ...	July 27th, 2 to 5.
Short Bros.	do.	Shipbuilding...	,, 10 to 4.
Sunderland Shipbuilding Co.	do.	Shipbuilding...	,, 10 to 4.
Thompson, J. T., & Sons ...	do.	Shipbuilding...	,, 2 to 4.
Thompson, R., & Sons ...	do.	Shipbuilding...	,, 10 to 4.
Tyzack, S., & Co.	do.	Iron Works	,, 10 to 4.
Wear Glass Works	do.	Glass Works...	,, 10 to 4.

* Wednesdays excepted.

WORKS OPEN FOR INSPECTION.

(By Member's Ticket only. For Position, see Plans of Newcastle and River Tyne.)

Name.	Place.	Nature of Works.	When Open.
*Sir W. G. Armstrong, Mitchell, & Co.	Elswick, Newcastle	Ordnance and Shipbuilding	July 26th, 1 to 5.
Robert Stephenson & Co.	South Street, Newcastle	Engineering	Each day, 2 to 4.
Newcastle Chronicle Printing Works	Westgate Road, Newcastle	Printing &c.	Each day at 4·45 precisely.
G. Angus & Co.	St. John's, Works, Newcastle	Leather	Each day, 10 to 4.
Donkin & Nichol	St. Andrew's Works, Newcastle	Engineering	,, 10 to 4.
Ernest Scott & Co.	Close, Newcastle	Do.	,, 10 to 4.
R. & W. Hawthorn, Leslie, & Co.	St. Peter's, Newcastle	Do.	,, 10 to 4.
Locke, Blackett, & Co.	St. Anthony's, Newcastle	Lead	,, 2 to 4.
John Abbot & Co.	Park Works, Gateshead	Engineering	Each day, 9 to 12 & 1 to 4.
Black, Hawthorn, & Co.	Park Lane, Gateshead	Do.	Each day, 10 to 4.
Clarke, Chapman, & Co.	Victoria Works, Gateshead	Do.	,, 2 to 5.
Hawks, Crawshay, & Sons	South Shore Road, Gateshead	Do.	,, 10 to 4.
I. C. Johnson & Co.	South Shore, Gateshead	Cement	,, 2 to 4.
Newcastle Chemical Works Co.	Gateshead	Chemical	,, 10 to 4.
Tharsis Copper Works Co.	Hebburn	Do.	,, 10 to 4.
Charles Tennant & Partners	Do.	Do.	,, 10 to 4.
R. & W. Hawthorn, Leslie, & Co.	Do.	Shipbuilding	,, 10 to 4.
Foster, Blacket, & Wilson	Do.	Lead	,, 11 to 4.
Palmer's Shipbuilding and Iron Co.	Jarrow	Engineering, Shipbuilding, &c.	,, 10 to 4.
Sir W. G. Armstrong, Mitchell, & Co.	Low Walker	Shipbuilding	July 28th, 2 to 4.
J. Wigham Richardson & Co.	Do.	Engineering and Shipbuilding	Each day, 10 to 4.
Tyne Pontoon & Dry Dock Co.	Do.	Engineering and Ship Repairing	,, 10 to 4.
Schlesinger, Davis, & Co.	Wallsend	Shipbuilding	,, 11 to 4.
C. S. Swan & Hunter	Do.	Shipbuilding	,, 10 to 4.
N.E. Marine Engineering Co.	Do.	Engineering	,, 11 to 4.
Wallsend Slipway and Engineering Co.	Do.	Engineering and Ship Repairing	,, 10 to 4.
Cleland's Slipway Co.	Willington Quay	Ship Repairing	,, 10 to 4.
Tyne Iron Shipbuilding Co.	Do.	Shipbuilding	,, 10 to 4.
W. Hepple & Co.	North Shields	Engineering and Shipbuilding	,, 10 to 4.
J. Eltringham & Co.	South Shields	Engineering	,, 10 to 4.
John Readhead & Sons	Do.	Engineering and Shipbuilding	,, 10 to 4.
John Spencer & Sons	Newburn	Steel Works	,, 2·30 to 4·30.
Consett Iron Works Co.	Consett	Iron and Steel Works	,, 10 to 4.
Weardale Iron and Coal Co.	Spennymoor	Rolling Mills	,, 11 to 4.

* By special invitation only.

VISIT OF INSTITUTION

NEWCAST

ROYAL MINING, ENGINEERI

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Plan of t

Ships' Models and Marine Engine Ex
Iron and Steel Exhibits ... ..
Ships' Appliances and Fittings ..
Dining Rooms and Art Gallery ..

The Arrows show the route follo

By Permission of R. Robinson & Co. Printers, Newcastle

Andrew Reid Lith. Newcastle

NEWCASTLE-UPON-TYNE ROYAL MINING, ENGINEERING, AND INDUSTRIAL EXHIBITION, 1887.

By the kind permission of Messrs. R. Robinson & Co., printers of the Official Catalogue, a Plan of the Exhibition is attached to this Programme.

THE main buildings are divided into four courts forming the sides of a rectangle, and, in accordance with their positions, are named the North, West, South, and East Courts. Of these, the exhibits in the North and West Courts are the most interesting to all engaged in the professions of naval architecture and marine engineering; and the intention of this little sketch is to act as a guide to those who desire in as short a time as possible to view these exhibits.

The principal entrance to the Exhibition is at the East end of the North Court. This court is divided into three bays, having seven passages. Following the route marked out by the arrows in the Plan the visitor should, after passing the turnstiles, turn to the right and proceed up the North passage (No. 1) where he will find the chief collections of models of all classes of ships and steamers lent by the shipbuilders of this and other districts; indeed, the whole of the North wall, on the right, is completely covered with them. On the left he will pass the highly interesting collection of models lent by the Italian Government (a few of these will also be found in passage No. 2), and then a fine model of Sunderland Harbour and Docks, sent by the River Wear Commissioners. Further on will be found the Rope exhibits; and to fully inspect them he must, after passing them on his left, turn to the left and return by passage No. 2. The space between passages Nos. 2 and 3 is chiefly taken up by the Locomotive Rolling Stock exhibits of the North-Eastern and Great Northern Railway Companies, but between these two will be found the model of the Mammoth Crane (one-twelfth full size) sent by the River Tyne Commissioners; Mr. John Dickinson's Patent Built Crank Shaft for Triple Expansion Engines; and sundry Crank Shafts, etc., manufactured by Messrs. The Tyne Forge Co. Having passed the latter he must turn to the right and go up (towards the orchestra) passage No. 3. He will now find himself in the vicinity of the Steel exhibits, of which it is not too much to say this Exhibition far

excels any which has preceded it. On his left he will see the beautiful model (one-eighth full size) of the Port Engines for the Royal Italian twin-screw ironclad "Sardegna," made by Mr. J. S. Allison, of Sunderland. The engines of the "Sardegna" are capable of developing 22,800 indicated horse-power, and are being built by Messrs. R. & W. Hawthorn, Leslie, & Co., at their Italian works. (The actual Crank Shaft for these engines, manufactured by Messrs. Vickers, Sons, & Co., is on view beside the Model Coal Mine in the North Gardens.) Messrs. Hawthorn, Leslie, & Co. also have on view a set of High-Speed Triple Expansion Engines, with cylinders 20 inches, 27 inches, and 42 inches diameter, by 18 inches stroke, built for Torpedo Cruisers. The visitor may now inspect the exhibits of Messrs. The Leeds Forge Co., consisting of their Corrugated Furnace Flue, Patent Flanged Frame Plates for Rolling Stock, etc. Next to them will be found the stand of Messrs. The Barrow Hæmatite Steel Co.; then those of Mr. Wasteneys Smith and Messrs. Cochrane, Grove, & Co.; and, at the end of the passage, the exhibits of Messrs. C. Cammell & Co.

Turning to left he will proceed along passage No. 4, when he will pass on his left the Steel exhibits of Messrs. John Spencer & Sons, who show a Cast-Steel Beam for one of Sir W. G. Armstrong, Mitchell, & Co.'s 120 tons Gun Carriages, weighing 10 tons; then those of Messrs. The Farnley Iron Co., who have on view one of Fenby's Patent Spiral Corrugated Furnace Flues; and a little further on Mr. Thomas Adams' collection of Safety and other Valves; and on the right the Steel and other exhibits of Messrs. John Brown & Co., who show one of Purvis's Patent Ribbed Furnace Flues, several specimens of Armour and Boiler Plates, also a most interesting exhibit of samples of 132 Residual Products obtained from Gas Coal; then follow those of Messrs. The Darlington Forge Co.; Messrs. Hawks, Crawshay, and Sons; Messrs. Ridley & Co.; and Messrs. The Wallsend Slipway and Engineering Co., who have sent a large High Pressure Marine Boiler, built wholly of steel, 14 feet 6 inches diameter by 11 feet long, having three corrugated steel furnaces 3 feet 6 inches diameter, total heating surface 2,200 square feet, grate surface 60 square feet, capable of developing 800 indicated horse-power. The riveting of the shell throughout has been done by Tweddell's latest Patent Combined Plate-closer and Riveter, some of which machines are now attached to the boiler to show the mode of using this invention. This firm has also on view a neat little model of a set of Compound Marine Engines. Next to the Wallsend Slipway Co. is the stand of Messrs. Wigham

Richardson & Co., who show some very fine models of Steamers, a model of a set of their Triple Expansion Engines (one-eighth full size), 4,500 indicated horse-power, several sets of Tweedy & Patterson's Patent Piston Rings, also an arrangement for a Ladies' Cabin for Steamers. Proceeding onwards, on either side, are the Ordnance Exhibits from Messrs. Sir W. G. Armstrong, Mitchell, & Co.'s Elswick Works, (full particulars of which can be obtained from pages 40, *et seq.*, of the Official Catalogue), and at the end of these exhibits will be found on the left the fine finished model of H.M. Armour-clad "Victoria," and on the right the launching model of the same vessel showing the piling of berth.

The space between the passages Nos. 5 and 6 for about one-half the length is taken up with the Locomotive exhibits of Messrs. R. Stephenson & Co., Messrs. R. & W. Hawthorn, Leslie, & Co., and Messrs. Black, Hawthorn, & Co. Before going up passage No. 6 the visitor should inspect Messrs. Emley & Sons' Saloon of Passenger Steamer in Marble at the entrance to the East Court. The south side (to the left hand) of passage No. 6 is devoted chiefly to Harbour and Dock exhibits, models of Floating Docks, Dredgers, etc. But if the visitor will turn to the left by Messrs. Head, Wrightson, & Co.'s stand and proceed along passage No. 7 he will be able to inspect the historical collection of Ship Models exhibited by Lloyd's Register of British and Foreign Shipping (particulars of which will be found on pages 76, *et seq.*, of the Official Catalogue).

Opposite these are the models of the improvements to Newhaven Harbour; the Barry Dock, Cardiff; etc.; maps of the improvements now being carried out at Blyth Harbour; and the model, to scale, of the "Entrance to the River Tyne."

Following the course pointed out by the arrows, he will now turn to the right and go down passage No. 5, which will bring him once more among the steel exhibits. He will pass on the

LEFT the exhibits of—	RIGHT the exhibits of—
Messrs. The Anchor Tube Co.	Messrs. The Consett Iron Co.
„ Crewdson, Hardy, & Co.	„ Tredegar Iron & Coal Co.
„ Taylor Bros. & Co.	„ Weardale Iron & Coal Co.
„ Credenda Tube Co.	„ J. Rogerson & Co.
„ S. Tyzack & Co.	„ Baird & Barnsley, who exhibit a set of Compound Surface Condensing Engines.
„ North-Eastern Steel Co.	
etc.	

If he will turn to the right, in front of Messrs. Baird & Barnsley's stand, and return by passage No. 6 to the West Court, he will find on his right the stand of Messrs. Bell Bros., which may be said to give a most instructive lesson on the manufacture of Pig Iron. A little further on, is the fine exhibit of Mitis Castings produced by Mr. T. Nordenfelt's patent process; and the Steel exhibit of Messrs. Seebohm & Dieckstahl.

Having examined these, he may now enter the West Court and Annexe. A considerable portion of this court is devoted to the exhibits in connection with coal mining, while the Annexe is chiefly occupied by various classes of machinery in motion.

He should proceed along the East (No. 1) passage of this court, when he will, amongst others, be able to inspect the following exhibits, on the

Left	Right
Mr. J. Kirkaldy — Feed Water Heaters, Fresh Water Distillers, etc.	Messrs. Bolckow, Vaughan, & Co. Iron Ore, Iron and Steel exhibits.
Mr. Andrew Reid—Printing Office including Letterpress and Lithographic Printing, Folding, Stitching, Pressing, and Cutting Machinery, etc.	,, Whitwell & Co.— Iron and Steel exhibits.
	,, Harfield & Co. — Patent Windlass Steering Gears and other Ship Appliances.
Messrs. Clarke, Chapman, Parsons, & Co. — Patent Windlasses, and Capstans, Steam Steering Gears, Steam Winches, etc.	,, Dunston Engine Works Co.—Ship Appliances.
	,, A. Shanks & Co.—A set of Triple Expansion Marine Engines.

If he will now turn to the right (by Shanks' engine) and proceed along the second passage, it will bring him to Messrs. Donkin & Nichol's fine exhibits of Steam Steering Gears, Ash Hoisting Engines, Fan Engines and Fans for forced draught, Mill's Patent High-Speed Engines, all at work; and other ship appliances.* After inspecting these, he should take the next turning to the right; it will bring him to the stand of Messrs. Ernest Scott & Co., who have a High-Speed Launch Engine at work, also a Fan and Fan Engine for forced draught, Double-Distilling Fresh Water Condenser with Triple Pump, etc. He must

* Those interested in Patent Piston Ring exhibits will find them behind Messrs. Donkin & Nichol's stand in passage No. 1, where will [illegible] wall, a design of a Sewage Steamer by Messrs. Menzies [illegible] of Photographs of Engines, etc., sent by Messrs. West[illegible]

now retrace his steps along the West (No. 4) passage. On his left will be found the Worthington and other notable Steam Pumps; also the stand of Messrs. Henry Watson & Sons, who show their Patent Automatic Air Valve and Improved Navy Pump, and McElroy's Patent Water-tight Door; on his right are the Steam Steering Gears of Messrs. Amos & Smith, and Messrs. Holmes & Co.'s system of Electric-lighting; and, lastly, on his left, the fine working model (one-fourth full size) of a set of Tripie Compound Engines, 1,100 indicated horse-power, manufactured by Messrs. Palmer's Shipbuilding & Iron Co.

Still following the route marked out by the arrows, he may now return to the North Court, passing on his way the stand of Messrs. R. Robinson & Co., the printers of the Official Catalogue, etc.; also the interesting collections of Coal and Mining Exhibits, and thence across the North Court to the Boiler House in the North Gardens, along the outside of which will be found the exhibits of Messrs. The Steel Co. of Scotland, Messrs. John Spencer & Co., etc. The chief arrangements of Electric-lighting for the whole building will be found inside the Boiler House. If he will proceed to the end of the Lake, return by the Old Tyne Bridge, and, when he has reached the south end of the Bridge, walk eastward (to the left), he will see before him the Crank Shaft for the "Sardegna's" engines, manufactured by Messrs. Vickers, Son, & Co.; and to the north of these the exhibits of Messrs. Jessop & Sons and Messrs. John Brown & Co. He may now consider his inspection, from a professional point of view, at an end. While in the North Gardens he may either inspect the various objects of interest around him, or return to the North Court, and then proceed along the East Court, which he will find devoted chiefly to articles of Furniture, Pottery, and China Ware, to the Art Gallery, after visiting which, he may inspect the South Court, the principal exhibits of which are domestic, and thus return to the West Court. He will now have completed his somewhat hurried tour through the whole building. But if time will permit, and he should desire to make a more minute inspection of any of the various exhibits, the writer of this sketch would refer him to the Subject-Matter Index, beginning on page 335 of the Official Catalogue (2nd edition), which may be found useful.

PALMERS SHIPBUILDING AND IRON COMPANY.

The works of Palmers Shipbuilding and Iron Company, Limited, are situated at Jarrow, on the south side of the river Tyne, and about 4 miles from the sea. They occupy an unbroken frontage of about three-quarters of a mile on the river, lie east and west, and comprise the following five distinct and separate branches divided into productive and constructive departments :—

First, there are four large Blast Furnaces, 85 feet high, and capable of producing 120,000 tons of pig iron. This is being done at the present time, the larger half of which is hematite pig iron, suitable for steel manufacture both by the Siemens-Martin and Bessemer process. The furnaces supply gas as fuel from the smelting of the ironstone to twelve Lancashire boilers, which in turn supply steam for driving the engines which produce the blast required in the furnaces for smelting ; the blast on its way to the furnaces passes through eight of Whitwell's hot blast stoves, taking up 1,600 degrees of heat, at which temperature it passes into the furnaces.

The second department is that of the Rolling Mills where, when in full work, 52,000 tons of finished iron of every required section is produced annually.

The third productive department is that of the Steel Works, which were built during the year 1885, and comprise recent improvements both in the construction of the furnaces and for the treatment of the ingots ; the latter are reduced by cogging mills, driven by engines indicating, when required, 6,000 horse-power. These are driven by nine steel Lancashire boilers working at 100 pounds pressure.

Next are the constructive departments. First, there are the Engine Works, capable of turning out annually 6,000 nominal horse-power. The department comprises brass and iron foundries, forges, coppersmiths' shops and brass finishers' shops, which supply the whole of the materials required for the engines under construction. This department is capable of turning out engines of any magnitude without being dependent for any important portion of their details upon other works outside the company's premises.

The same may be said of the last department—the Shipbuilding Yard. This consists of fourteen launching berths (including six in the Howdon Yard on the opposite side of the river), adapted for the construction of the largest vessels for war or commercial purposes, and capable of turning out 70,000 tons of commercial shipping annually. In 1882 and 1883 over 60,000 tons each year were sent afloat, since which time the capabilities of all the departments of these works have been increased, and are now capable of doing fully the above work.

VISIT OF INSTITUTIO

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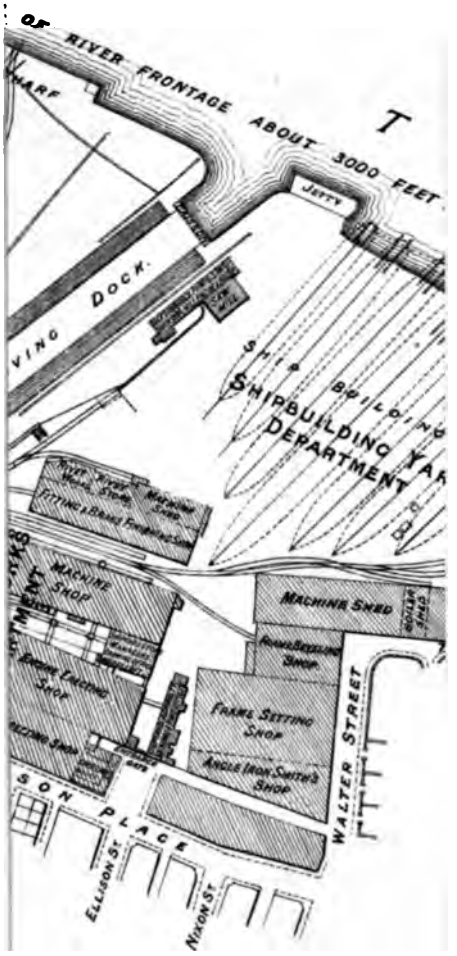

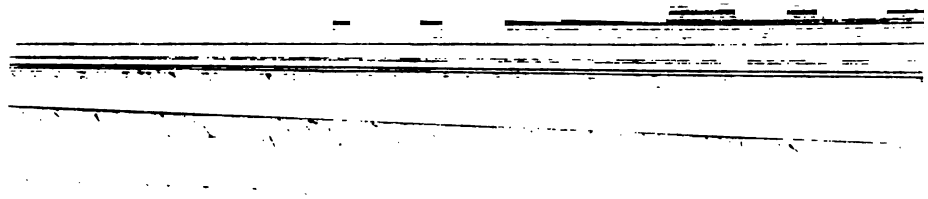

CONSETT IRON AND STEEL WORKS,

The property of the Consett Iron Co. (Limited), is situated in the north-west of Durham, and consists of extensive collieries, coke ovens, brick-works, blast furnaces, puddling forges, iron plate rolling mills, Siemens-Martin steel plant, and steel plate rolling mills.

The collieries extend over a large area, and produce coking and other coals of the finest Durham quality to the extent of over one million tons annually. The coke ovens produce about 500,000 tons of coke per annum.

The brickworks are so constructed, and attached to ranges of coke ovens, that the waste heat of the latter is applied to the drying floors and kilns for economy of fuel. The capacity of these works is equal to about 150,000 bricks per week.

The blast furnace plant is concentrated in the Consett township, which is the centre of the iron and steel manufacture. There are seven blast furnaces of modern construction, each 55 feet high. Some of these have made, for many months, 800 tons of high-class Bessemer pig iron per week. There are four pairs of powerful blowing engines. The blast is heated by brick stoves, four to each furnace, of the Whitwell type, which were the first of this kind, applied about the year 1868. The furnace gases are applied for generating steam and heating the brick stones. These seven furnaces have produced over 210,000 tons of pig iron per annum, and are capable of doing much more.

There were recently 175 puddling furnaces, and over 110,000 tons of puddled iron have been produced annually. This section of the manufacture is now giving way to the operations in steel. Up to a recent date 85,000 to 90,000 tons of iron plates per annum have been made for shipbuilding, boilers, bridges, etc.

In the manufacture of steel, the Siemens-Martin process has been adopted for the production of mild steel. The gas producers are of the Siemens' type. There are now at work eight Siemens' melting furnaces of large capacity, with spacious platforms, valve chambers, etc. The ingots produced are converted into slabs by a cogging mill. There are two rolling mills devoted to the conversion of these steel slabs into plates, and the present production of these mild steel plates is about 1,000 tons weekly. In the manufacture of steel at Consett hematite ore only is used.

Consett for this trade is practically self-contained. It has its own excellent fuel, and, by its association with mining in Spain, it has also, to a considerable extent, its own pure iron ore.

In the course of construction are the following:—A further range of eight Siemens' melting furnaces of even larger capacity than the existing furnaces; a powerful pair of engines and mill capable of cogging ingots up to four and five tons in weight; also a large hot bloom shears capable of cutting a slab 30 inches by 9 inches. Another plate rolling mill is undergoing reconstruction for steel plates of large sizes for shipbuilding, and various engineering requirements.

ELSWICK SHIPYARD AND WORKS.

The shipyard lies at the extreme east end of the Elswick Works. Its formation was commenced in 1883, and it now occupies 16 acres of "made" ground, with a river frontage of about 2,000 feet. Along the finishing jetties there is a depth of 26 feet of water at low tide and 36 feet at high tide.

OBJECTS OF INTEREST.

H.M. Armour-clad "Victoria."—This vessel was launched in April last, and is now lying alongside the Quay at the west end of the yard. Her principal dimensions are as follows:—Length, 340 feet; breadth, 70 feet; mean draught, 26 feet 9 inches; displacement, 10,500 tons. Her armament consists of two 110 ton guns mounted in a single turret forward, one 10 inch gun aft, twelve 6 inch guns on the broadsides, and about thirty smaller guns. She also has six torpedo tubes. Her sides, and the redoubt containing the mechanism for working the turret and the loading arrangements, are protected with 18 inch steel-faced armour, and the turret itself is protected with 17 inch steel-faced armour. Her engines are of the vertical triple expansion type, and are expected to develop 12,000 indicated horse-power under forced draught. Steam is supplied from eight single-ended return-tube boilers, the steam pressure being 135 lbs. per square inch.

Protected Cruisers "Chih Yuen" and "Ching Yuen."—These vessels are lying off the centre jetty, and are nearly complete. Their dimensions are as follows:—Length, 250 feet; breadth, 38 feet; mean draught, 15 feet; displacement, 2,300 tons. Their armament consists of two 8 inch guns (twin-mounted) forward, one 8 inch gun aft, one 6 inch gun on each broadside, and a number of smaller guns. They also carry four torpedo tubes. Hydraulic machinery is largely used in these vessels for working the guns, steering, warping, etc. They are fitted with twin screws and triple expansion engines of horizontal design, and capable of developing upwards of 6,000 indicated horse-power.

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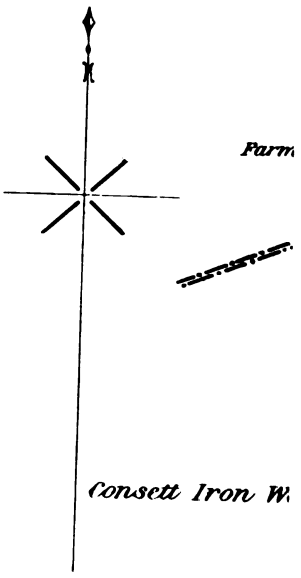


REFERENCE.

A Consett Railway Station.

B Puddling Forge and Iron Plate Rolling Mills.

C General Offices.

D Blast Furnaces with Whitwell's Stoves, Blowing Engines, &c.

E Siemens' Melting Furnaces, Gas Producers, &c.

F Iron and Steel Testing House.

G Ingot Cogging Mill and Steel Plate Rolling Mills.

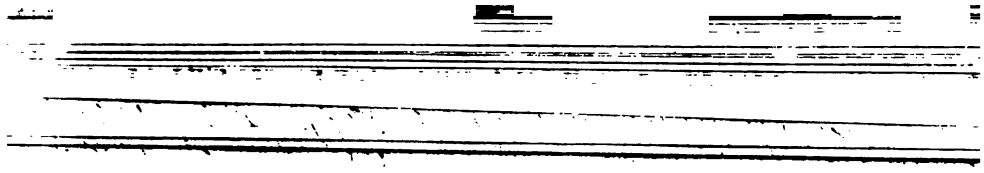
H Puddling Forges and Iron Plate Rolling Mills.

I New Block of Siemens' Melting Furnaces in course of construction.

J New Ingot Cogging Engines, Cogging Mill, Heavy Bloom Shears, and Steel Plate Rolling Mills in course of construction.

K Brick Works with arrangements for utilising Waste Heat at Coke Ovens.

L Consett Town Hall.



PROTECTED CRUISERS "ISLA DE LUZON" AND "ISLA DE CUBA."—These vessels are of a smaller class than the preceding, their dimensions being—length, 185 feet; breadth, 30 feet; mean draught, 11 feet 6 inches; displacement, 1,030 tons. Their armament consists of six 12 centimetre guns, nine smaller guns, and three torpedo tubes. They are fitted with twin screws and horizontal triple expansion engines, carrying steam of 150 lbs. pressure, and running at 190 revolutions per minute under forced draught.

ARMOUR-CLAD BERTHS.—At the east end of the yard are two berths piled down to the boulder clay and adapted for the construction of the largest class of armour-clads. On one of these may be seen the ways from which H.M.S. "Victoria" was launched a few months ago, with a launching weight of no less than 5,600 tons.

TURRET FOR H.M.S. "VICTORIA."—Close to the armour-clad berths the turret for H.M.S. "Victoria" is being constructed.

MECHANICAL APPLIANCES.—Amongst the machines may be mentioned a steam punching and shearing machine capable of punching and shearing cold 2-inch steel plates, Brown's crane locomotives, Arthur's bevelling machines, Hamilton's gear cutters, Parson's electrical generators, etc.

ORDNANCE DEPARTMENT.

Passing up the railway incline from the shipyard to the ordnance department, arriving at the top will be seen a 105 ton gun, whose dimensions, etc., are as follows :—

Length overall ...	490 inches or 40 feet 10 inches.
Diameter of bore	11 inches.
Weight of projectile	2,000 lbs.
Weight of charge	900 lbs.

FORGE SHOP (O^2 on Plan).—A gun ingot being forged under a 35 ton nammer of 12 feet stroke.

GUN CARRIAGE SHOP (E^2 on Plan).—Gun carriages of various sizes in progress, among which may be noted a hydraulic naval carriage and platform for gun of 9·2 inches calibre. The carriage and platform are mounted on a central pivot and a live-roller ring.

This mounting is made of steel and is fitted with a Vavasseur recoil cylinder, frictional elevating gear, steel shield, traversing gear, loading crane, and a sighting and loading platform. The recoil cylinder absorbs the energy of the recoil and is automatic in its action, the gun returns into firing position immediately after recoil.

The powder charge is brought up from the ship's magazines below, through a central tube passing through the pivot of the platform and curving towards the breech of the gun.

The platform carries a large supply of projectiles ready for use.

6-INCH BREECH LOADING GUN.—Mounted on a centre pivot Vavasseur carriage. Dimensions, etc., of the gun are :—

Weight	5 tons.
Length overall ...	194 inches or 16 feet 2 inches.
Calibre	6 inches.
Weight of projectile	100 lbs.
Weight of charge	50 lbs.

36-POUNDER SIMULTANEOUS LOADING GUN.—The ammunition for this gun is arranged as in rifles and small guns of rapid fire, the powder charge being contained in a brass case, into the mouth of which the projectile is fixed.

The breech of the gun is so arranged that its opening and closing are done exceedingly quickly and easily, and the firing is done by electricity.

The arrangements are such that the rapidity of working does not, in the slightest degree, involve any risk of premature firing.

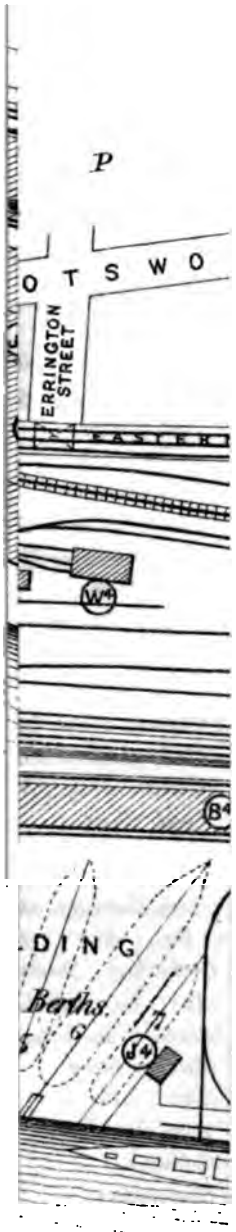
The mounting is also specially arranged ; the carriage can be trained and the gun elevated, and fired by one man. The gun always recoils in the line of fire, and is instantly returned to loading position by means of springs. The recoil is absorbed by a hydraulic press.

The dimensions of the gun are :—

Length overall ...	157 inches or 13 feet 1 inch.
Weight	34 cwts.
Calibre	12 cm., or 4·724 inches.
Weight of projectile	36 lbs.
Weight of charge	12 lbs.

The rate of firing actually obtained in practice at Porstmouth was 12 rounds per minute.

28 CM. (11 inches), HOWITZER CARRIAGE (*in construction*).—This is a novel arrangement for high-angle fire ; in this the gun can be fired at angles up to 75° above the horizon. The weight of the gun for this carriage is 11¼ tons, and the mounting is hydro-pneumatic, *i.e.*, expansion of air, through the medium of water, is employed to run the gun up the inclined slide, and, having this means of power, the slide may be placed at an angle corresponding with that of the axis of the gun. The same power is made use of to arrest the motion of the gun in recoil.

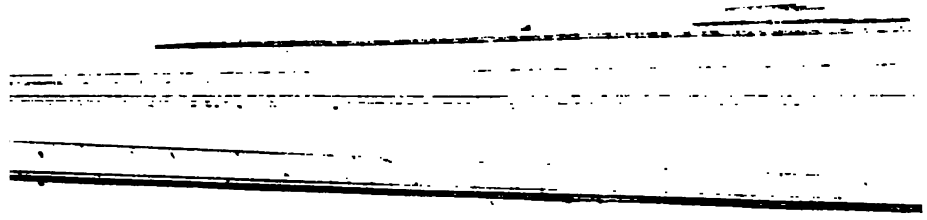

P
O T S W O
ERRINGTON STREET
EASTER
W⁶
B⁴
D I N G
Berths
J4

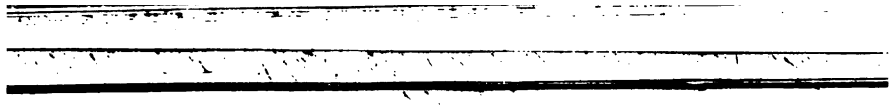
	Description of Shop.	Feet.
A	Yard	55 × 30
B	Pipe Shop and Test	35 × 81
C	General Store	16 × 81
D	Erecting Shop (South)	355 × 75
E	Joiners' Shop	90 × 30
F	Coal Store	39 × 26
G	Jetty	
H	Erecting Shop (North)	61 × 290
I	Fitting and Brass Finish^{g} Shop	250 × 65
J	Brass Foundry and Store	545 × 25
K	Engine Ho. Boiler Ho. & Plan Store	55 × 65
L	Erecting Shop	375 × 55
M	Smiths' Shop	410 × 40
N	Painters' Shop & Store	70 × 12
O	Coach Ho. & Plan Store	19 × 46
P	Stable	28 × 17
Q	Paint & Oil Stores	31 × 9
R	Office Lodge	28 × 24
S	Offices	135 × 40
T	Bridge Yard	415 × 215
U	Pattern Shop & Time Office	200 × 52
V	Pattern Store	125 × 45
W	Mill. Store & Dining Room	140 × 35
X	New Offices	145 × 55
Y	Offices	75 × 35
Z	Drawing Office	99 × 35
A^{1}	Dining Room	30 × 11
B^{1}	Boiler House	60 × 60
C^{1}	Gatemans Lodge	15 × 8
D^{1}	Engine House	52 × 20
E^{1}	Machine Shop N^{o} 1	90 × 80
F^{1}	Boiler House	80 × 50
G^{1}	Forge Shop N^{o} 4	320 × 80
H^{1}	Gun Machine Shop N^{o} 11	320 × 70
H^{1a}	Hydraulic Works &c. N^{o} 11^{a}	
I^{1}	Railway & Coal Depot	
J^{1a}	Gatling & Hydraulic Works (N^{o}	
J^{1}	Gun Machine Shop (N^{o} 3)	220 × 63
K^{1}	Gun do. do. (N^{o} 26)	220 × 47
L^{1}	Gun Finishing Shop (N^{o} 14)	135 × 70
M^{1}	Test Rooms &c.	150 × 47
N^{1}	Fuze Factory	110 × 45
O^{1}	Gas Producers	90 × 15
P^{1}	Time Office	18 × 8
Q^{1a}	Gun Carriage Shop (28^{a})	92 × 210
Q^{1b}	Do. do. do. (28^{b})	92 × 285
Q^{1c}	Hotchkiss Gun &c. Shop (28^{c})	600 × 28

	Description
Q^{1d}	Do. Shell
R^{1}	Boiler House
S^{1}	Engine Hou
T^{1}	Foundry (N
U^{1}	Foundry Tim
V^{1}	Foreman's H
W^{1}	Stables
X^{1}	Harness Roo
Y^{1}	Old Laborat
Z^{1}	Projectile St
Z^{1a}	Do. d
Z^{1b}	Hotchkiss Gu
A^{2}	Boiler Hous
B^{2}	Millwrights
C^{2}	Foundry Fl
D^{2}	Engine Hou
E^{2}	Gun Carria
F^{2}	Time Office
G^{2}	Shell Contai
H^{2}	Accumulat
I^{2}	Tool House
J^{2}	Smiths' She
K^{2}	Engine Hou
L^{2}	Blast Furna
M^{2}	Do. Furnac
N^{2}	Smiths' Shop
O^{2}	Steam Ham
P^{2}	Gas Furnac
Q^{2}	Boiler Hous
R^{2}	Coiling She
S^{2}	Rifling She
T^{2}	Smiths' Sho
U^{2}	Coal Shed
V^{2}	Gas Produce
W^{2}	Tool Store
X^{2}	Gun Carriag
X^{2a}	Do. do.
Y^{2}	Cart Shed (2
Z^{2}	Do. do. d
A^{3}	Stable & two
B^{3}	Pattern Stor
C^{3}	Do. do.
D^{3}	Iron Ore Je
E^{3}	Cottage
F^{3}	Gasometer
G^{3}	Retort Hous
H^{3}	Purifying H

CE.

?p.	Feet.		Description of Shop	Feet
e Shop (28d	650 × 28	I^3	Engine & Boiler House	20 × 25
	160 × 30	J^3	Coal Depôt	70 × 18
	160 × 30	K^3	Three Gasometers	
	270 × 200	L^3	Accumulator House	14 × 25
	20 × 10	M^3	Engine House	77 × 30
	20 × 20	N^3	Boiler House	50 × 45
	60 × 20	O^3	Engine House	10 × 25
Box	22 × 15	P^3	Millwrights' Shop	12 × 140
	35 × 15	Q^3		
33)	330 × 70	R^3	Jetty	
		S^3	Turret & Machine Shop (N°24)	
e Shop		T^3	Blacksmiths' Shop	90 × 150
	80 × 40	U^3	Jetty	
(30)	55 × 40	V^3	Boiler House	50 × 18
ce	30 × 36	W^3	Stores, Joiners Shop &c.	240 × 55
	15 × 50	X^3	Offices	120 × 45
(N°29)	240 × 240	Y^3	Gatemans Lodge	15 × 10
	25 × 15	Z^3	Paint Shop & Stores	40 × 32
	30 × 60	A^4	Plumbers Shop	34 × 32
Engine	17 × 35	B^4	Tool Shop	490 × 36
	18 × 10	C^4	Plate Shop	220 × 204
ice	44 × 17	D^4	Mahogany Store	50 × 30
	29 × 42	E^4	Dining Hall	115 × 35
e		F^4	Machine Shed	45 × 55
ires		G^4	Locomotive Shed	130 × 50
sion	200 × 70	H^4	New Smiths' Shop	45 × 30
hop (N°31)	125 × 110	I^4	Saw Mill	90 × 85
	45 × 10	J^4	Oakum & Pitch House	38 × 24
	65 × 75	K^4	East Jetty (N°2)	
	150 × 85	L^4	Building of Steel Works	260 × 660
rs' Shop	80 × 20	M^4	Offices do. do. do.	85 × 20
5)	280 × 75	N^4	Institute	70 × 70
	55 × 10	O^4	Laboratory	70 × 30
		P^4	Schools (Boys & Girls)	200 × 50
	95 × 18	Q^4	Infant School	54 × 95
(N°16)	108 × 52	R^4	Office, Saw Mills	45 × 20
(N°16a)	108 × 66	S^4	Saw Mills	196 × 55
	54 × 22	T^4	Desicating House	10 × 26
over	70 × 25	U^4	Smiths' Shop	42 × 32
	80 × 20	V^4	Timber Store	48 × 50
	60 × 75	W^4	Locomotive Shed	38 × 60
	75 × 96	X^4	Riggers' Loft & Spar Shed	130 × 30
		Y^4	East Jetty	
	30 × 20	Z^4	Mooring Dolphins	
		A^5	Gun Carriage Shop (N°17)	
	30 × 45			
	22 × 22			





Z[1].—PROJECTILE SHOP.—Projectiles of various sizes, up to 2,000 lbs. weight.

T[1].—FOUNDRY.—Casting of projectiles, etc., in machine moulds. Moulding and casting of general work.

X[2] AND X[2]*a*.—GUN CARRIAGE SHOPS.—Field carriages and fittings. Hydro-pneumatic disappearing gun carriages in construction. Hydraulic carriages, for 68 ton and 100 ton guns, in construction.

Q[1].—Hotchkiss guns, carriages, ammunition, and other small work.

L[1].—GUN-FINISHING SHOP.—3-pounder Hotchkiss gun on non-recoil carriage; 3-pounder Hotchkiss gun on recoil carriage; 7-pounder jointed gun for mountain service, as used in Abyssinian and other campaigns.

K[1], J[1], AND H[1].—Gun machinery shops; boring, turning, rifling, etc.

ENGINE DEPARTMENT.

Enter M.—SMITH'S SHOP.

L.—Part of 300-ton forging press erected. Shields for guns of belted cruisers, etc.

H AND I.—MACHINE AND ERECTING SHOPS.—Cylinder for 300-ton forging press.

D.—Hydraulic oscillating engines, hydraulic pumping engines, etc., hydraulic cranes, bollards and capstans for merchant service steamers.

T.—BRIDGE YARD.—Hydraulic swing bridge, 80-feet opening. Pedestal and cylinders for 30-ton hydraulic crane.

Exit by C[1] and R.

The number of workmen employed by the firm is between twelve and thirteen thousand.

Newcastle Postal Information.

Box Closes.		Chief Places of Destination.	Deliveries in Newcastle.	
A.M.	P.M.		A.M.	P.M.
2 45	3 40	Alnwick, Morpeth, and the North ...	7 0	2 15 7 15
5 30	1 45 4 45	Blaydon	7 0	2 15 5 15
5 30	3 40	Bedlington and Blyth	7 0	2 15 7 15
2 45	3 40	Berwick		
5 30 9 45	2 30 4 15 6 15	Carlisle and Cumberland	7 0 11 0	2 15 5 15
	1 10 4 45 10 0	Darlington	7 0	2 15 5 15
3 45 9 45	1 10 6 15 10 0	Durham	7 0 11 0	2 15 5 15 7 15
1 30 2 45 11 50	3 40	Edinburgh and Morpeth	7 0	2 15 7 15
3 45	4 15	Fence Houses...	7 0	2 15 7 15
5 30	1 45 3 40 6 15	Gateshead	7 0 11 0	2 15 5 15 7 15
1 30 2 45 11 50	3 40 6 15	Glasgow and Scotland	7 0 11 0	2 15 7 15
	1 45 10 0	Ferryhill, Hartlepool, West Hartlepool, Middlesbro', and Stockton ...	7 0	2 15 5 15
5 30	2 30 4 15 6 15	Hexham, &c.	7 0 11 0	2 15 5 15 7 15
6 0	12 10 3 40	Jarrow	7 0 11 0	2 15 5 15 7 15
9 45	6 15 10 0	*London, Liverpool, Manchester, Sheffield, Bradford, and Birmingham ...	7 0	*2 15 5 15
	12 30	London and all parts of Continent... ...		
3 45	12 10 3 40	North and South Shields, Tyne Dock, Tynemouth, Sunderland, and Seaham	7 0 11 0	2 15 5 15 7 15
9 45	12 30 3 30 10 0	York, Scarbro', and Whitby... ...	7 0	2 15 5 15
9 45	3 40 6 15 10 0	Ireland and Westmorland	7 0 11 0	2 15 5 15

NEWCASTLE TRAMCARS.

To Exhibition every 5 minutes from Central Station, between 10 a.m. and 10·30 p.m.

Scotswood Toll to Monument at 8·30, 9·0 a.m., and every 15 minutes until 1·0 p.m., then every 10 minutes till 10·30 p.m. Fare 2d.

Monument to Scotswood Toll at 8·0, 8·25 a.m., and every 15 minutes until 12·25 p.m., then every 10 minutes until 9·55 p.m. Fare 2d.

Jesmond Road (Minories) to Central Station at 8·25 a.m., and every 40 minutes until 10·25 p.m. The 10·25 p.m. to Barras Bridge only. Fare 2d.

Central Station to Jesmond Road at 8·45 a.m., and every 40 minutes until 10·5 p.m. Fare 2d.

Central Station to Osborne Avenue at 8·50 a.m., and every 10 minutes till 10·30 p.m. Fare 2d.

Osborne Avenue at 8·30 a.m., and every 10 minutes till 10·50 p.m.

Byker to Central Station at 8·30 a.m., and every 10 minutes until 10·30 p.m. The 10·40, 10·50, and 11·0 p.m. to Blackett Street only. Fare 2½d.

Central Station to Byker at 8·30 a.m., and every 10 minutes until 10·30 p.m. Fare 2½d.

Gosforth to Monument at 7·30 and 8·0 a.m., and every 15 minutes until 12 noon, then every 10 minutes until 9·30 p.m., then at 9·45, 10·0, and 10·30 p.m. Fare 3d.

Monument to Gosforth at 8·0, 9·0, and 9·30 a.m., and every 15 minutes until 1·30 p.m., then every 10 minutes until 10·30, then 11·0, 11·15, and 11·30 p.m.

Monument to Elswick Road at 8·0 a.m., and every 10 minutes till 10·30 p.m. Fare 2d.

Elswick Road to Monument at 8·25 a.m., and 45, 55, 5, and 15 minutes past each hour till 10·55 p.m.

Arthur's Hill.—Leave the Monument at 8·5, 8·35, 8·55, 9·25, 9·45, 10·15, 10·35, 11·5, 11·25, 11·55, 12·15, 12·45, 1·5, 1·35, 1·55, 2·25, 2·45, 3·15, 3·35, 4·5, 4·25, 4·55, 5·15, 5·45, 6·5, 6·35, 6·55, 7·25, 7·45, 8·15, 8·35, 9·5, 9·25, 9·55, 10·15. Returning 25 minutes after.

* Cars leaving Osborne Avenue and Jesmond after 10·10 p.m., and Gosforth at 10·0 p.m., stop at Barras Bridge.

GATESHEAD TRAMCARS.

Low Fell to High Level from 8·30 a.m., and every 10, 30, and 50 minutes past each hour to 9·30 p.m.

High Level to Low Fell and Saltwell from 8·40 a.m., and every 20 and 40 minutes past each hour till 9·40 p.m.

High Level to Teams from 7·55 a.m., and every 15, 35, and 55 minutes past each hour till 9·35 p.m.

Teams to High Level from 8·25 a.m., and every 5, 25, and 45 minutes past each hour till 9·45 p.m.

Felling to Sunderland Road End from 8·50 a.m., and every 10, 30, and 50 minutes past each hour till 10·10 p.m.

Sunderland Road End to Felling 8·50 a.m., and every 10, 30, and 50 minutes past each hour till 9·50 p.m.

RAILWAY TIME TABLES.

ALNWICK.

Fares—5/0, 4/2, 3/1½.
Return—10/0, 8/4, 5/6.

Newc. Dep.	Alnk Arr.	Alnk. Dep.	Newc Arr.
6 8x	7 27	7 35	9 25
8 20	10 5	8 25x	9 45
10 25	12 10	10 20	12 15
12 15x	1 25	12 20x	1 35
1 30	3 20	2 35	3 50
4 30	6 30	2 35x	4 50
5 21x	6 30	5 10x	6 38
6 30	8 15	6 40	8 40
8 45	10 30	7 50	9 47
....	....	8 35x	10 0
....	....	9 45x	10 0

BLYTH.

From New Bridge St.
Fares—2/0, 1/8, 1/2
Return—3/9, 2/9, 2/-.

Newc. Dep.	Blyth Arr	Blyth Dep.	Newc Arr.
7 45	8 34	8 5	8 59
11 15	12 5	9 33	10 25
1 45	2 35	1 48	2 40
4 30	5 20	4 33	5 30
7 45	8 35	6 23	7 20
10 15	10 59	9 20	10 5
....	....	....	....
....	....	....	....

CARDIFF.

Fares—45/8, 36/10, 26/1.
Return—87/10, 67/6, 52/2.

Newc. Dep.	Card. Arr.	Card. Dep.	Newc Arr.
a1 45x	3 13	6 0x	5 11
9 30x	8 15	7 0	8 0
10 5x	10 6	10 10x	9 12
1 45x	2 33	12 45x	12 33
7 8x	6 49	6 10x	5 58
11 15x	1 15	9 5x	1 47
....	....	....	....
....	....	....	....
....	....	....	....

Via L. & N. W.

1 45x	6 42	6 30	9 12
10 5x	9 55	9 35x	10 53
7 8x	10 3	1 10x	1 47

CARLISLE.

Fares—8/1, 6/3, 5/-.
Return—16/2, 13/6, 8/6.

Newc. Dep.	Carl. Arr.	Carl. Dep.	Newc Arr.
6 25	9 5	6 20	8 55
10 15x	12 15	7 55	10 30
3 5x	5 20	10 10x	12 0
4 45	7 10	2 0x	4 25
7 10	9 50	4 0	6 40
....	....	6 15x	8 40
....	....	....	....

CONSETT.

Fares—2/- 1/8, 1/3.
Return—4/-, 3/4, 2/1.

Newc. Dep.	Benfi Arr.	Benfi. Dep	Newc Arr.
6 10	7 5	8 15	9 5
9 40	10 32	9 5	10 0
11 0	11 50	2 40	1 25
12 15	1 5	3 25	4 15
2 30	3 23	6 15	7 0
5 30	6 15	9 2	9 53
7 30	8 25	....	....

DURHAM.

Via Team Valley.
Fares—2/3, 1/9, 1/3½
Return—4/4, 3/6, 2/3.

Newc. Dep.	Dur. Arr.	Dur. Dep.	New Arr.
7 5	7 45	5 31x	5 58
7 40x	7 50	8 17	8 58
9 30x	9 50	8 50	9 30
9 35	10 15	9 47x	10 10
10 5x	10 28	10 56x	11 23
10 40	11 24	11 10	11 50
12 15	12 55	11 33x	12 0
1 17	2 0	2 15	2 55
1 45x	2 6	2 56	3 36
2 35x	2 59	4 14x	4 35
3 30	4 10	4 24x	4 44
4 0x	4 19	4 51x	5 11
4 28	5 7	5 35	6 15
5 12	5 57	7 34x	8 0
7 8x	7 31	7 40	8 20
7 15x	7 37	8 45x	9 12
7 40	8 20	9 30x	9 55
9 22	10 7	9 32	10 13
11 15x	11 38	12 9x	12 33

Via Leamside.

5 10	6 20	8 52	9 47
7 0	7 52	10 42	11 40
8 30x	9 25	1 25	2 20
10 25	11 21	3 0	4 0
12 55	1 50	5 20	6 10
2 0	3 5	7 36	8 30
4 55	5 52	10 15x	11 0
9 25	10 55	....	....

EDINBURGH.

Via Berwick.
Fares—20/3, 16/0, 10/4.

Newc. Dep.	Edin Arr.	Edin. Dep.	Newc Arr.
‡1 52x	4 45	10 0x	12 45
3 5	6 15	10 15x	1 35
3 46x	6 55	12 40	3 50
6 8x	9 55	2 50x	6 38
10 25	3 40	5 15x	10 0
12 15x	3 40	7 35x	11 0
1 30	8 25	10 20x	1 10
‡4 12x	7 0	10 40x	1 40
4 52x	7 45	....	....
5 21x	8 38	....	....
....	....	....	....
‡2nd	class.	....	....

† Not on Mondays.

(Waverley Route.)

6 20	12 10	6 20	12 32
11 40	4 32	4 25	9 48
4 25x	8 42	....	....

GLASGOW.

Via Berwick.
Fares—25.7, 20/0, 12 10.
Return—44/5, 35/1, 24/6.

Newc. Dep.	Glas. Arr.	Glas. Dep.	Newc Arr.
‡1 5‡x	6 20	8 45x	12 45
3 5x	7 45	11*0x	4 25
6 8x	11 20	1 0x	6 38
12 15x	5 20	4 0x	10 0
*3 5x	*8 0	6 0x	11 0
‡4 12x	8 20	9 15x	1 50
4 52x	9 48	....	....
5 21x	10 25	....	....

‡ 2nd class. * Via Carlisle.
† Not on Mondays.

HARTLEPOOL.

Via Sunderland.
Fares—4/7, 3/8, 2/9½.
Return—9/2, 7/4, 4/9.

Newc. Dep.	Htlpl Arr.	Htlpl. Dep.	Newc Arr.
6 55	8 56	7 10	8 55
*7 35x	8 56	8 55	10 35
9 25	11 6	10 0x	11 25
10 45	12 22	12 0x	1 45
1 8x	2 36	2 50x	4 20
1 40	3 26	3 15	5 10
3 25x	4 56	6 10	7 50
5 50	7 46	9 0	10 45
8 45	10 38	....	....

* Change at Wellfield.

LEEDS.

Via Thirsk.
Fares—13/6, 11/-, 8/4.
Return—27/-, 22/-, 14/-.

Newc. Dep.	Leeds Arr.	Leeds. Dep.	Newc Arr.
5 10	9 55	5 0	9 30
*7 35x	10 47	7 55x	11 23
†7 40x	10 47	10*45x	1 50
9 30x	12 40	11 0	3 36
10 40	3 19	1 38x	4 44
12‡50x	3 43	3 45x	8 0
1 45x	4 45	5 30x	9 12
3 50x	7 5	6 20	9 55
4 0x	7 35	*7 50x	10 53
5 12	9 52	8 55x	12 33
7 8x	10 40	....	....

* Via Sunderland.
† Change at Thirsk.

Via York.

a1 45x	4 35	2 14x	5 58
10 5x	1 25	9 5x	12 0
12‡50x	3 43	1 35x	4 7
4 0	7 10	2 0x	5 11
7 8x	10 20	3 35x	8 0
....	....	5 30x	9 12
....	....	6 10	9 55
....	....	9 5x	12 33
....	....	11 15x	1 47
....	....	....	....

‡ 1st and 2nd class.

LIVERPOOL.

Fares—25/5, 19/7, 13/4½.
Return—45/7, 35/3, 26/-.
(Via L. and Y).
Exchange Stion.

Newc. Dep.	Liver. Arr.	Liver. Dep.	Newc Arr.
7 40x	1 35	8 10x	§1 50
9 30x	3 35	11‡ 0	4 7
10 5x	3 55	11*35	6 40
10*15x	3 52	12 10x	8 0
10‡40	5 32	3 0x	9 12
12‡50x	6 7	4 0x	9 55
1 45x	7 50	5 0x	10§53
*3 5	8 50	6 15	12 33
4 0x	9 57	8 15x	1 47
11 15x	10 0	....	....
....	....	....	....

Via L. & N. W.
Lime Street Station.

a1 45x	9 15	12*45	8 55
§7 35x	1 45	§8 0x	1 50
9 30x	3 45	*9 40x	4 25
10 5x	3 45	11‡ 0x	4 7
10 40	6 45	11 0x	4 44
12‡50x	6 45	11*10	6 40
1 45x	7 50	12 0x	8 0
*3 5x	9 15	*2 0x	8 40
4 0x	9 50	3 0x	9 12
7 8x	2 0	§5 0x	10 53
....	....	7 0x	1 47
....	....	10 45x	5 58

* Via Carlisle. † Tebay.
§ Via Sunderland.
‡ 1st and 2nd class.

LONDON.

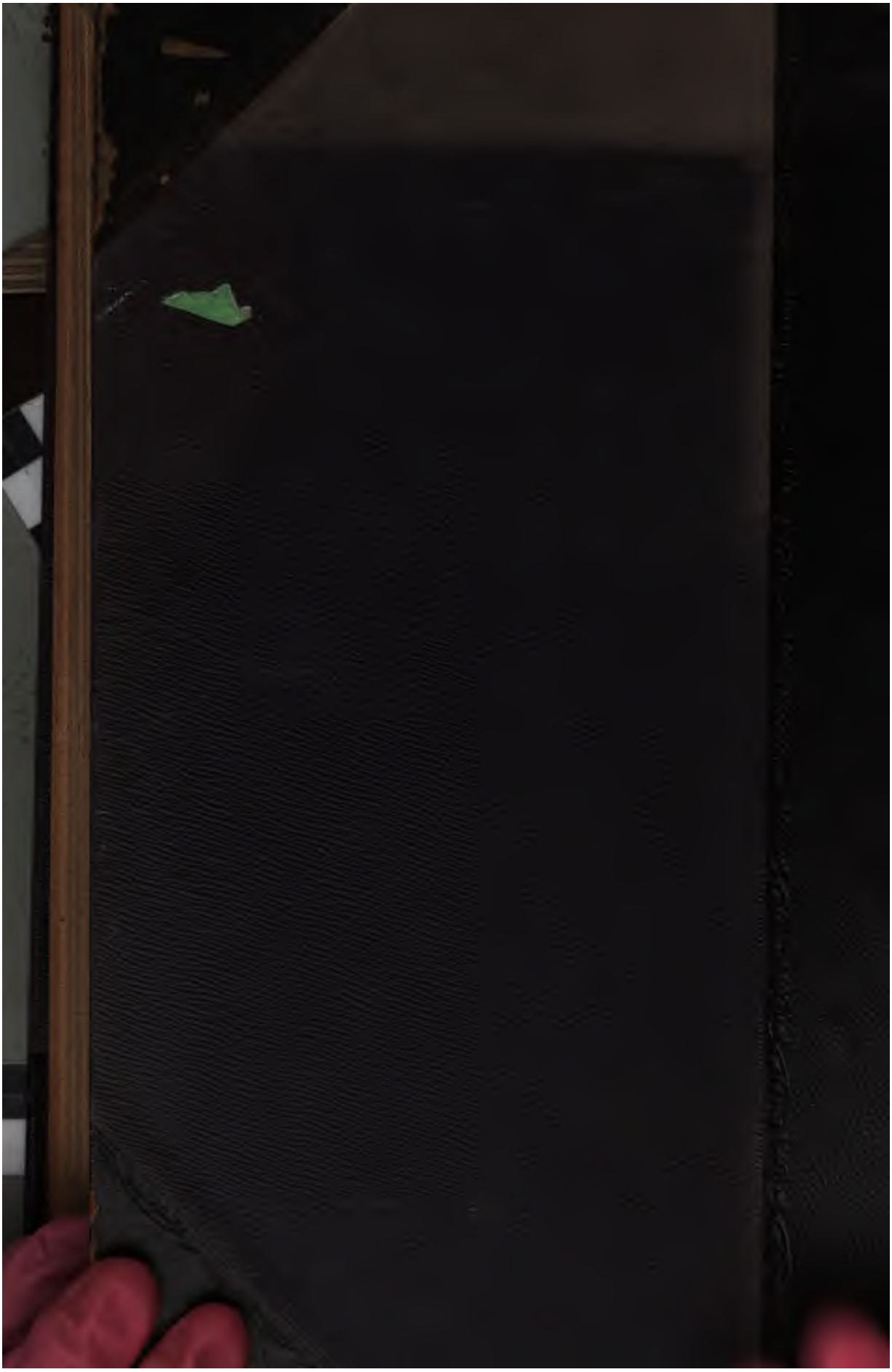
King's Cross.
Fares—38/3, 30/3, 22/7½.
Return—76/6, 60/6, 45/3.

Newc. Dep.	Lon. Arr.	Lon. Dep.	Newc Arr.
a1 45x	8 15	5 15x	12 0
7 40x	2 5	9 0x	4 44
9 30x	4 30	10 0x	4 7
10 5x	5 0	10 25x	4 35
12‡50x	7 0	10 35	5 11
1 45x	8 30	11 45x	8 0
4 0x	10 50	1 30x	9 12
7 8x	2 15	3 20x	9 55
11 15x	5 45	5 45x	12 33
....	....	§8 0x	1 52
....	....	8 30x	2 58
....	....	§9 30x	3 39
....	....	10 30	5 58
....	....	....	....

† Not on Saturdays.
‡ The 10 0 a.m. and 12 50 p.m. are 1st & 2nd cls. only

St. Pancras.
Fares—38/3, 22/7½.

a1 45x	12 55	5 15	3 36
7 40x	3 0	10 0x	5 11
9 30x	5 40	10 35x	8 0
10 5x	5 50	12 25x	9 12
12 50x	8 40	*3 0x	10 53
1 45x	10 0	3 40x	12 33
4 0x	2 20	5 30x	1 47
7 8x	4 15	9 15x	5 58
11 15x	7 15	12 0x	11‡23
....	....	....	....

* Via Sunderland.
† No connection with Newcastle on Sundays.

a Monday Mornings at 1·42.